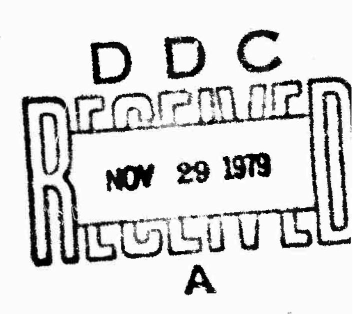
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Contract No. F49620-78-C-0067
July, 1979

AIRCRAFT EMERGENCY DECISIONS: COGNITIVE AND SITUATIONAL VARIABLES

ROSEMARIE HOPF-WEICHEL
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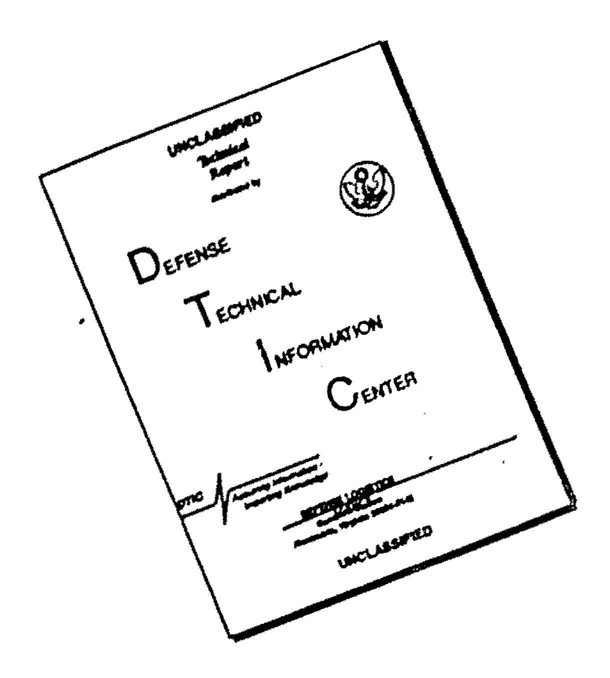
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Military aircraft accidents are important not only to the individuals directly involved, but also to those responsible for preparing and maintaining combat-ready forces for the nation's defense. The cost of an accident can be measured directly in terms of injuries, lives lost, and equipment repair and replacement costs. Indirect costs, which accompany these accidents, include the time and training resources invested in the personnel lost as well as the impact of the loss of equipment and trained personnel on force effectiveness. The present report addresses the problems underlying aircraft emergency situations,

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in four ways. First, background information consisting of a literature review and an analysis of selected accident reports was collected and is described. Second, a workshop was convened to review the state-of-the-art of aircrew emergency decision training, safety research, and behavioral decision theory. The workshop resulted in the identification of current issues and recommendations for future work. Third, a selected set of emergency situations was the basis of a preliminary classification of aircraft emergency situations in terms of several situational and decision making attributes. The classification is based on data derived from interviews with experienced military flying personnel. Fourth, a taxonomy of emergency situation types was developed, incorporating both situational and task specific elements as cognitive attributes of the decision tasks performed under emergency conditions. There were several steps preceding the development of the taxonomy. The aggregation of situations which could be considered within an emergency training program was reviewed. A definition of the emergency situation was developed, which limited the scope of consideration to a manageable entity--known malfunctions. Representational models of the objective (external) emergency situation, decision processes, and cognitive functioning were proposed as a way of characterizing the situational and behavioral aspects of an emergency malfunction. The taxonomic structure was then derived after consideration of the cognitive elements of the three representational models.

On the basis of the taxonomy, three classes of emergency situations were found to be of interest: Situation 1 (predictable), Situation 2 (partly predictable), and Situation 3 (unpredictable). Initial training guidelines are suggested in light of the cognitive requirements of each class.

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1. OVERVIEW

1.1 Objectives of Phase 1

This report describes the activities and findings of the first phase of a three-year research and development effort to enhance pilot and aircrew emergency decision skills. The overall effort will provide a basis for designing training programs and training materials which address the development of aircrew emergency decision skills in a more systematic and comprehensive manner than has been possible in the past.

Major objectives of Year 1 were:

(1) To review the current state of the art of emergency decision training for aircrew members, from both theoretical and practical standpoints.

(2) To review the decision research literature and identify methodologies which can be utilized to define and analyze aircraft emergency problems in terms of cognitive decision functions.

(3) To develop theoretical models of the aircraft emergency situation which account for the relevant situational and cognitive variables involved.

(4) To derive initial guidelines from the models which can be used in design of training programs for aircrew emergency decision skills and which facilitate the development of training materials and emergency situation scenarios.

1.2 Rationale

Military aircraft accidents are important not only to the individuals directly involved, but also to those responsible for preparing and maintaining combat-ready forces for the nation's defense. The cost of an accident can be measured directly in terms of injuries, lives lost and equipment repair and replacement costs. Indirect costs which accompany these accidents include the time and training resources invested in the personnel lost as well as the impact of the loss of equipment and trained personnel on force effectiveness.

The military services have paid close attention to the problem of aircraft safety with the gratifying result that accident rates have steadily exhibited a downward trend. While military aircraft safety continues to show progress, there is still need to press for additional improvements. Human error commonly contributes to approximately 50% of military aircraft accidents (Nuvolini, 1979) suggesting that emergency procedures and training are a fruitful area in which to expend additional effort.

An emergency is commonly defined as an unexpected occurrence of a set of circumstances which calls for immediate judgment and action to avoid undesirable consequences. The standard emergency response expected of every aircrew is three-fold: (a) to maintain aircraft control, (b) to analyze the situation and take proper action, and (c) to land as soon as practicable. In the broader context of flight safety, aircrews are expected to do more than skillfully resolve immediate full-blown emergencies. It is equally important that they actively avoid situations which might lead to emergencies and that they recognize the early signs of an impending emergency and take corrective action before the situation assumes crisis proportions.

Emergency preparedness, according to this view, goes beyond the capability to make very rapid and accurate decisions under intense time pressure. It is a truism among experienced flying personnel that there is usually more than enough time to deal with most emergencies and, further, that it is not the first mistake, or even the second, that kills pilots, but the third. An aircraft emergency might be viewed, then, as a sequence of events and decisions, which, if not recognized and resolved at an earlier stage, culminate in a crisis. If so, emergency preparedness training, and more specifically, emergency decision training, must accommodate the broader range of situations and skills that this conception embraces.

In the strict sense, decision making can be viewed as the efficient translation of information into appropriate action by a rational decision maker using effective decision strategies. While this may be an adequate description of decision analysis, a slightly broader view of decision making is necessary to encompass the decision activities important in the practical setting of aircrew emergency decision training. As Nickerson and Feehrer (1975) point out, decision making involves a number of overlapping aspects or phases of activity, which might best be conceived of as a series of related problem solving tasks. In our view, the following breakdown is useful in characterizing the general area of decision making:

(I) Situation Diagnosis.

(a) Problem recognition.

(b) Information acquisition and evaluation.

(2) Decision Making.

(a) Problem structuring and development of alternatives.

(b) Evaluation of alternatives and selection of a course of action.

(3) Decision Execution.

(a) Implementation of action alternative.

(b) Monitoring of implementation and evaluation of results.

The impact of situational factors on emergencies and emergency decisions can not be ignored. A decision which is appropriate under one set of circumstances can be fatal under another. Aircrew members must be prepared not only to exercise the wide range of decision skills suggested above, but to consider relevant situational factors appropriately in formulating and executing emergency decisions.

The present program of research and development considers the need to integrate the situational and decision-making variables of aircraft emergencies into a common cognitive framework. Specification of such a structure would permit the design of emergency decision training strategies on a more comprehensive, effective, and efficient basis than has been possible in the past. Similarly, the derivation of realistic and effective training materials, in particular emergency situation scenarios, would be facilitated. Both of these outcomes could be of significant practical value in addressing the aircraft emergency problem through improved training of aircrews.

1.3 Activities of Phase 1

A number of activities were carried out in the first year of this three-year program in order to develop the theoretical base needed to support the succeeding years' efforts. These activities included reviews of SET and Boldface approaches to emergency training; site visits to a number of training squadrons for observation, orientation, and interviews with flying personnel; reviews of flight manuals and training materials for a number of military aircraft; an extensive period of field data collection and analysis of judgmental data derived from interviews with flying personnel; a review and analysis of USAF aircraft accident reports for 1977; and convening of a workshop of civilian and military personnel to review approaches to the analysis of aircraft emergency decisions, aircraft accident research, and aircrew emergency decision training.

Two major reports were prepared as a result of these activities. The first, Aircrew Emergency Decision Training: A Conference Report, summarizes the results of the workshop held in San Francisco in November 1978. The second is this report which presents the results of the other activities carried out during Phase 1.

1.4 Overview of Accomplishments

The work of Phase 1 was successful in providing a theoretical basis for the design of aircrew emergency training programs. A taxonomic structure was derived which appears to be of considerable value in specifying the cognitive aspects of aircraft emergency problems. There are two obvious applications of the taxonomy in training settings. The first is the specification of training techniques or strategies for classes of emergency situations which are related in terms of cognitive functions

required for their successful resolution. The second area of application is at a more detailed level, namely in the development of scenarios or aircraft emergency problems for use in the training of pilots and other aircrew members.

Chapter 7 represents the culmination of the year's work in that the taxonomy incorporates both situational and task-specific elements as cognitive attributes of the decision tasks performed under emergency conditions. There were several steps preceding the development of the taxonomy. The aggregation of situations which could be considered within an emergency training program was reviewed. A definition of the emergency situation was developed which limited the scope of consideration to a manageable entity--known malfunctions. Representational models of the objective (external) emergency situation, decision processes, and cognitive functioning were proposed as a way of characterizing the situational and behavioral aspects of an emergency malfunction. The taxonomic structure was then derived after consideration of the cognitive elements of the three representational models.

On the basis of the taxonomy, three classes of emergency situations were found to be of interest: Situation 1 (mostly predictable), Situation 2 (partly predictable), and Situation 3 (unpredictable). Initial training guidelines are suggested in light of the cognitive requirements of each class.

The taxonomy also provides a framework for emergency scenario generation. Situational and behavioral aspects of emergencies are covered at a level of detail which allows systematic identification of their cognitive elements. Thus, the utility of the taxonomy in specifying scenario components lies in the ability to correlate various and seemingly disparate elements of a given problem (or set of problems) in cognitive

terms. This provides the capability to manipulate scenario parameters in a systematic fashion so as to ensure that training experiences are managed (and evaluated) in terms of a comprehensive and unifying factor--cognitive functions.

The material of Chapter 6 is another key product of the present study, that is, the preliminary classification of emergency situations according to the performance requirements of these situations as dictated largely by the physical nature of high-performance aircraft operations. This material supports the work of Chapter 7 since it facilitates the identification of emergency situations which are candidates for special emphasis in decision training programs. The classification, which derives from consideration of the risk, time pressures, and complexity of decision making tasks associated with specified malfunctions, lends an objective frame of reference to the theoretical tools provided by the representational models and taxonomy of Chapter 7.

Taken together, the schema and data of Chapter 6 and the taxonomic structure of Chapter 7 appear to provide a means to address training program design both in terms of the objective (physical) and cognitive factors of aircraft emergencies. Work in Phase 2 will be aimed at refining and extending the tools developed as a result of Phase 1 activities.

1.5 Report Contents

Chapters 2 through 7 of this report describe the results of six distinct phases of effort carried out during the first year of activity. Chapter 2 presents a review of relevant background literature, which includes decision making, decision making as a flying skill, limitations on the decision maker, decision training, and the effects of stress. Chapter 3

briefly reviews the events and resulting recommendations of the Aircrew Emergency Decision Training Workshop.

Chapter 4 reviews current approaches to aircrew emergency decision training and relates them to relevant psychological theories of learning and cognitive activity. Chapter 5 contains the results of an analysis of 387 USAF aircraft accidents which occurred in 1977 as well as a discussion of the value of such analyses in designing training programs and training materials. Chapter 6 presents a preliminary classification of aircraft emergency situations in terms of several situational and decision making attributes. The classification is based on data derived from interviews with experienced military flying personnel. Chapter 7 represents the major theoretical outcome of the first year's efforts. Three representational models are proposed for the emergency situation and a taxonomic structure, which treats decision aspects of emergency situations, is derived. Cognitive theory is used to link variables of emergency situations, as identified in the taxonomy, to appropriate training methods.

2. BACKGROUND LITERATURE

2.1 Introduction

As an initial step in the work of Year 1, a review of the relevant literature was undertaken to provide a background for the research and development efforts to be carried out. A computerized search was carried out, relying principally on NTIS and on Psychological Abstracts. Abstracts were selected and reviewed for a number of articles, books, and technical publications which seemed relevant to the present work. Topics of interest included decision making, emergency procedures, aircrew training and performance, decision training, and performance under stress. While the literature on each of these separate topics is large, and in some cases voluminous, aircrew emergency decision training, as a combined topic, has received relatively little attention.

The results of this review are summarized in this chapter. Certain review articles proved to be particularly relevant and comprehensive. These include works by Goodman, Fischhoff, Lichtenstein and Slovic, 1976; Kanarick, 1969; Nickerson and Feehrer, 1975; Prophet, 1976; Slovic, 1976; and Vaughan and Mavor, 1972. The topics covered below include decision making, decision making as a flying skill, limitations on decision making, decision training, and the effects of stress.

2.2 Decision Making

Decision science has become an area of growing interest to defense, business, medical and other organizations. This interest has evolved from the need to improve the quality of decisions by ensuring that action alternatives are chosen which maximize the expected gain to be

derived by the individual or organization. Nickerson and Feehrer (1975) point out, however, that:

> Much has been written about the importance of decision making for industry, for government, for the military and for rational--or at least reasonable--people in general. Moreover, a great deal of research has been conducted on decision-making behavior. In spite of these facts--or perhaps because of them--there is not general agreement concerning what decision making is, how it should be done, how it is done, how to tell whether it is done well or poorly, and how to train people to do it better. (p. 1)

However, when the term "decision making" is used in commercial and military contexts, there is informal agreement concerning the components of decision situations, which include "fairly well-defined objectives, significant action alternatives, relatively high stakes, inconclusive information and limited time for decision." (Nickerson and Feehrer, p. 1)

There are many ways to classify the various tasks that the decision maker may be required to perform. Nickerson and Feehrer (1975) found that the most satisfactory scheme recognizes eight aspects of decision making: information gathering, data evaluation, hypothesis generation, problem structuring, hypothesis evaluation, preference specification, action selection, and decision evaluation. Not all these tasks are involved in every decision, nor are they all equally difficult. For example, even though alternative selection is central to decision making, the problem of choosing among possible courses of action is frequently far simpler than that of discovering what one's options are in the first place, or of being consistent in assigning preferences to possible decision outcomes.

Each of these eight aspects of the decision situation represents a problem necessitating some decision making. Frequently, several preliminary problems may have to be solved before even considering the decision which is of primary concern. Such decisions include the acquisition of information necessary to set the stage for the primary decision. The problems of deciding how much time is available for buying additional information and what are reasonable costs for it, must also be considered.

The linkage of decision making and problem solving is also found in Dieterly's (1978) work on the clarification process model, which was developed in part as a building block for training programs in decision making for managers of aircrew and aircraft systems. Dieterly ties together concepts in decision making and problem solving through their underlying reliance on information flow and information processing. His model reflects the increasing interest in a unified psychological approach to decision making, an interest which parallels the recent interest in and growth of the cognitive movement in psychology.

A second noteworthy aspect of Nickerson and Feehrer's characterization of the tasks performed by the decision maker is the attempt to identify and define, to the extent possible, eight tasks (or sub-processes) performed by decision makers. Although a number of taxonomic systems for the description of decision activities have been proposed, the essential point is that a variety of investigators have found it useful to attempt to subdivide "decision making" into specific activities or sub-processes, each of which may separately be more amenable to investigation than decision making taken as a whole. This approach is compatible with the instructional systems development (ISD) approach to training, which relies heavily on detailed analysis of tasks to be performed and development of instructional materials designed to facilitate learning

of the knowledge and skills required for successful task performance. Few would seriously argue that a rigid and overly simplified ISD approach to decision training is either useful or an immediate possibility. Many would question whether decision skills could ever be developed by relying on such "reductionist" training methods. Nevertheless, the trend toward isolation and description of decision sub-processes will encourage and support more systematic attempts to develop decision training programs that are more systematic than those realized in the past.

2.3 Decision Making as a Flying Skill

An extensive survey of the behavioral science literature dealing with the subject of flying skills, in particular the long-term retention of such skills, was carried out by Prophet (1976). He characterized the nature of the military pilot's task as follows:

> It is clear that the tasks the pilot of a modern military aircraft must perform are many and complex. There are few task situations that demand as much of the performer in terms of physical strength and endurance, fine perceptual and motor discriminations, cognitive functioning, verbal communication skills, decision making, and the like, as does that of flying an aircraft. (p. 14)

According to Prophet, the critical aspects of advanced flying skills are primarily cognitive, dealing with identification and acquisition of relevant information (in terms of both tactical and aircraft situations), the processing of such information, decision making, system management (including tactical, aircraft, and human systems), and similar "higher level" functions.

Nearly two decades earlier, Williams and Hopkins (1958) had expressed similar views. They felt that cognitive activity, and decision making in particular, was becoming an increasingly important aspect of operating military aircraft:

> A reasonable extrapolation of the past trend in operator tasks to the future suggests that operators will become less and less concerned with continuous manual control tasks and more and more concerned with the interpretation of information assembled from a variety of sources and displayed "artificially" within the cockpit and with the choice of operating mode based upon the information received. This kind of activity corresponds closely with what is commonly known as the exercise of judgment or the making of decisions. (p. 3)

Although their analysis of pilot functions in the F-106 led Williams and Hopkins to conclude that decision making was an increasingly important function, they viewed decision making in a rather narrow vein, suggesting that the courses of action open to the pilot are built into the system. According to Williams and Hopkins, the pilot's decision functions are concerned with the diagnosis of the state of the system and only rarely with the choice of a course of action to pursue, because the mission is carefully planned in advance, with modes of operation provided for each major state in which it is expected the system will find itself. The pilot's decision is seen as a diagnosis--a detection and recognition of the state of the system--and, having done this, he adjusts the equipment to operate in the mode specified in advance.

Pilot decision making, according to this view, is limited to situation recognition and is followed by execution of a well-rehearsed, preplanned response sequence. Training for decision making, in this case,

would focus on learning to screen and rapidly classify situations into predetermined categories (template matching) and to associate a standard response with each category. Situation recognition and rapid response execution are undoubtedly important elements of decision making and flying skill. Other investigators, however, have taken a broader view of the decision requirements placed on the pilot. With respect to the emergency situation, which is perhaps the ultimate test of aircrew decision skills, Thorpe, Martin, Edwards, and Eddowes (1976) provide a detailed picture of the complex decision-making activities involved:

> During the course of any emergency situation...the pilot should: (a) maintain aircraft control, (b) analyze the situation and take the proper action, and (c) land as soon as practicable.
>
> Now consider the likely course of events: the pilot is somewhere along in the mission, attending to the mission requirements, and unexpectedly an emergency occurs. The emergency may be indicated by warning lights, an abnormality in instrument readings, abnormal flight control responses, strange noises, vibrations, or any combination of a number of these or other cues. Some of these cues are easily detected, others are more subtle and may not be immediately perceived. Once the pilot detects the cues, he must do two things simultaneously: continue to fly the aircraft, and analyze the situation. Accomplishing these in a multicrew aircraft may not be as taxing as in a single place aircraft, provided crew coordination does not break down. But in a single place aircraft under some conditions, maintaining aircraft control alone will be a demanding task. Likewise, analyzing the situation may be a simple diagnostic process or it could be considerably more complex, involving complicated information seeking. The appropriate response could be a simple response sequence, or it could be an extended sequence of inputs.
>
> After recognizing and analyzing the emergency, while maintaining aircraft control, the pilot must determine

> the consequences of various responses on the rest of the mission. Usually this will require a plan of recovery. The pilot must anticipate the interaction of his corrective actions with the immediate problem solution and with the safe landing or conclusion of the mission. Thus, he must know where he is, where he is going, and how he is going to land safely when he gets there. Failure to think through these phases of the recovery can compound the emergency.
>
> The fundamental cognitive activites of the pilot during the emergency are the detection of the cues or symptoms which signal the onset of the emergency, the diagnostic determination of what is wrong, the decision making processes which consider viable alternative courses of action, the selection of the most suitable response, and the execution of that response. The need for good judgment during these activities is obvious. (pp. 7-8)

Thorpe et al. question whether standard emergency training procedures, which often emphasize learning of predetermined procedural responses, satisfactorily address the development of the decision skills needed in emergencies. If current "training discourages judgment or makes it harder to exercise, it follows that an alternative training approach should be considered. Is it possible to train good judgment as well as procedural accuracy?" (pp. 7-8).

Similarly, Prophet (1976) points out that while the training of basic flying skills is reasonably well understood, less is known about training more advanced skills such as decision making because little research has been done on the nature, development, maintenance, and retraining of the higher level flight skills characteristic of the professional USAF pilot. Prophet lists a number of areas such as changes in ability/skill with time and experience, information processing concepts, multi-task residual attention capabilities, and learning and performatory stra-

tegies for higher skill levels, which would be profitable to investigate. He identifies the need for a better understanding of the factors involved in the acquisition, maintenance, and retraining of higher level pilot skills. There may or may not be fundamental differences in the principles underlying effective training for basic and higher skills. Such differences, however, can only be discovered by first defining the nature of these higher skills and establishing specific objectives for their training.

One particular area of concern is the need for advancing the technology of design and use of simulation for the training of higher level pilot skills. Training devices vary from quite simple devices to complex flight and weapons systems simulators. While various training devices can be used with high cost effectiveness in flight skills maintenance and retraining programs, very little is known concerning their effectiveness in training higher order flight skills. Clearly, this is an important area for further research.

2.4 Limitations on Decision Making

The study of human decision making behavior reveals a number of deficiencies which accompany the different component tasks which constitute decision making (Hammell and Mara, 1970). In the literature, the term "deficiencies" is used in two ways: (1) to refer to stereotyped ways of behaving suboptimally, such as the tendency of humans to be overly conservative in their application of probabilistic information to the evaluation of hypotheses, and (2) to refer to basic human cognitive limitations of memory, attention span, and information processing, which prevent most people from weighing more than a small number of factors in arriving at a preference among alternatives without procedural help.

The following provides an overview of man's characteristic performance in those empirical tasks that have been studied as components of decision making behavior. Three main categories--problem recognition, situation diagnosis, and action selection--will be examined for this purpose. Much of the material presented is based on the excellent summary prepared by Vaughan and Mavor (1972).

2.4.1 Problem Recognition. This aspect of the decision process basically involves the monitoring of an ongoing action in terms of its impact on a given situation, comparing key aspects or dimensions of the situation to acceptable limits, and determining whether the action is still appropriate to the situation. Options available to the decision maker, once a problem is identified, are to initiate a new action, to modify or terminate an ongoing action, or to continue present actions.

Available empirical evidence suggests that men tend to err on the side of conservatism in this task. For example, Vaughan, Virnelson, and Franklin (1964) asked experienced army officers to monitor a series of messages that indicated the need to change the axis of advance in a simulated attack scenario. With only one exception, officers did not modify the ongoing action plan, nor did they anticipate the possibility of changing the plan, in spite of a series of messages indicating this need with increasing urgency.

2.4.2 Situation Diagnosis. Man is a weak diagnostician. Summarizing results from several studies of clinical diagnosis, Goldberg (1968) concluded that diagnostic judgments are:

(1) Unreliable over time.

(2) Unreliable across diagnosticians.

(3) Only marginally related either to experience of the man or to his confidence in the accuracy of his judgments.

(4) Only slightly affected by the amount of available information.

(5) Generally of low validity.

These discouraging results can be traced to the complexity of the diagnostic task, particularly where configurational, non-linear cue patterns are a component of the problem. Diagnosis--and military diagnosis is not an exception--is primarily a task area requiring a cycling of inductive inference processes that build diagnostic categories from items of data and their interactions, and deductive processes, for testing a given diagnostic category against available data. Experts in clinical psychology, medicine, psychiatry, military intelligence, and the like, typically view their work as involving complex interpretations of configural cue patterns. However, carefully planned studies of the process, using qualified diagnosticians as subjects, have not revealed much use of these configural cues in the outcomes of their judgments. Simple, linear, additive models typically account for more than 90% of the outcomes of clinical diagnosis.

Edwards (1963) presented evidence from non-clinical studies that man is a relatively good probability estimator for single items, but poor at aggregating a number of probability estimates to form a conclusion. Additional evidence and discussion of this misaggregation effect were provided by Slovic and Lichtenstein (1971) and Rapoport and Wallsten (1972). The conclusion that men do not do well at extracting informa-

tion from available data is supported by the findings of Vaughan, Franklin, and Johnson (1966); namely, that ambiguous, partial, and conflicting information items are ignored as inputs to the planning process. Vaughan et al. had a group of experienced army officers study a series of map problems that contained partial and ambiguous information about enemy strength and disposition. Schemes of maneuver were planned on the basis of information categories that were known to be reliable: the mission order, the terrain, and the available resources. It was found that information about the enemy was not accorded various possible interpretations, and did not influence the planning process.

2.4.3 Action Selection. The process of selecting an action (or a complex of serial or contingent actions) assumes the existence of a diagnostic category or set of categories that define the state(s) for which an action response or plan is required. Selecting an action (or set of actions) involves the following subtasks:

(1) Formulation of alternative action possibilities.

(2) Formulation of appropriate criteria for assessing alternatives.

(3) Assignment of differential weights or priorities to the criteria.

(4) Assessment of alternatives against the criteria.

Ideally, this set of subtasks is to be performed iteratively at successive levels of detail. A variety of prescriptive models of decision making of this kind exist in the military. Empirical studies of persons

responsible for decision making of this sort in actual environments are summarized below according to the main subtasks.

Formulation of Action Alternatives and Evaluation Criteria. When a pre-established set of action alternatives does not exist, man is required to develop alternatives from a set of resources which he can draw upon or use in one of several ways. In complex situations, man apparently has difficulties in creating alternatives (Gagliardi, Hussey, Kaplan, and Matteis, 1965; Vaughan et al., 1966). Formulation of evaluation criteria appears to present comparable difficulties (e.g., Schroder, 1965). Moreover, there is evidence that criterion identification is correlated with action formulation such that a decision maker will tend to only consider criteria that support the action alternative he has created.

Assignment of Differential Weights to Criteria. The limited evidence available suggests that experienced decision makers and problem solvers are excellent criteria evaluators. Vaughan et al. (1964), for example, asked experienced submarine commanders and officers to assign quantitative weights to seven criteria affecting the desirability of a running depth for two tactical situations. Criterion weights were highly reliable over time, consistent within subjects, and differentiated appropriately between tactical situations.

Assessment of Alternatives Against Criteria. Simultaneous consideration of multiple alternatives portrayed against multiple criteria in a decision matrix quickly becomes too complex for easy resolution. For example, Hayes (1962) found decreases in decision quality and increases in time required as criteria were increased from two to eight for four-alternative and for eight-alternative decision problems. Also, Connolly and his associates conducted a series of experiments at Hanscomb Field

to assess the appropriateness of weapon selection decisions by experienced Air Force officers in a simulated air defense environment (Connolly, Fox, and McGoldrick, 1961; Connolly, McGoldrick and Fox, 1961; Fox and Vance, 1961). Although instructed to use three criteria in the selection of weapons to targets (minimize damage to defended area, destroy maximum number of threatening objects, and conserve counterweapons), actual selections reflected a disproportionate weighting of the three factors.

2.4.4 Summary. The following picture emerges of people's performance in making complex decisions (Vaughan and Mavor, 1972):

(1) Humans are slow to initiate action and conservative in their estimates of highly probable situations.

(2) When humans act or accept a diagnosis, they are reluctant to change an established plan or a situational estimate when the available data indicate that they should.

(3) They are generally poor diagnosticians.

(4) Humans are not particularly inventive and tend to adopt the first solution developed.

(5) They find it difficult to use more than one or two criteria at a time in evaluating actions and tend to identify criteria that reflect favorably on the action being developed.

(6) Humans tend to use only concrete, high-confidence facts in planning and prefer to ignore or reduce the importance of ambiguous or partial data.

(7) They are good judges of the probability of single items of information, given alternative hypotheses.

(8) They are very good judges of the relative importance of those criteria that can be identified.

Different approaches to correct deficiencies in human decision making have been suggested (Schrenk, 1969). There are basically three ways to improve human decision performance:

(1) Selection: insure that decisions are made only by individuals who are competent to make them.

(2) Decision Aiding: provide decision makers with procedural and technical aids to compensate for their own limitations.

(3) Decision Training: attempt to improve the decision-related skills of people in decision-making positions.

Decision aiding and decision training can be viewed as complementary to one another. While decision training attempts to improve decision making behavior by training out deficiencies and highlighting limitations, decision aiding provides the decision maker with procedural and technical aids which let him go beyond his own limitations in the process of decision making. Much research work has been performed on decision aiding, while decision training has been rarely investigated.

2.5 Decision Training

2.5.1 Current Programs. There are a number of decision training programs that are currently being implemented with some success. These

programs are either task specific or treat only limited aspects of the decision making process. Some of the programs are used in operational contexts.

Einhorn and Hogarth (1975) have developed an approach to teaching multi-attribute utility analysis to top-level executives and middle-level managers. While their system, termed "An Idiot's Guide to Decision Making," maintains a reasonable degree of independence with respect to any specific domain, it covers only one method of alternative evaluation. Other tasks involved in the decision making process, as well as the interrelationships among such tasks, are ignored.

Decisions and Designs, Inc. has developed a decision-aiding system called Rapid Screening of Options. The system involves an interactive computer program that simplifies a decision analysis by focusing on a limited number of alternatives and on the major causes of uncertainty (Selvidge, 1976). The training aspect of the system consists of displaying the expected value associated with each alternative evaluation and does not cover other elements of decision making such as problem recognition, alternative development, and the optimal sequencing and effort allocation for these subprocesses.

Hammond, Stewart, Brehmer, and Steinman (1975) present judgment as the key element of a decision making process. They assume that if people are taught the theory behind judgment analysis and are then trained in increasingly difficult applications of task situations, they will eventually be able to analyze any problem properly. Based on this assumption, their training system focuses strongly on judgmental aspects and ignores the other elements of the decision making process.

The Decision Analysis Group at Stanford Research Institute conducts several different training programs for decision makers. Through these programs, trainees are expected to learn that decision theoretic methodology exists, that uncertainties and utilities can be quantitatively estimated, and that they can begin to structure and work through their own decision problems. While the programs are enriched by a reasonable degree of generality and completeness, they do not provide the required link between decision training and specific application areas.

Michigan State University's Medical School approach to the training of physicians is based on a total curriculum design wherein decision analysis is integrated within specific content areas (Allal, 1973; Elstein, Shulman, and Sprafka, 1978). It assumes that the diagnostic phase of medicine consists of generating hypotheses about what the medical problem might be, distinguishing the relevant from the irrelevant features of the case, and then systematically gathering information to test and compare alternative hypotheses. The program is task-specific and relies heavily on the case-study method.

The Los Angeles Police Academy's "shoot/no shoot" training is an example of a task-specific decision training program. Although the program covers no formal training in either probability theory or decision theory, it includes extensive courses in the established important attributes that should be considered when deciding whether or not to shoot in a given situation. There are no relative weighting schemes for the attributes nor decision rules that translate the utilities of the attributes into a decision. There are, however, general guidelines that help the cadets make the decision. Because of time criticality, the cadets are taught to prune the decision tree before the actual decision situation arises. The training system is tailored for the specific task involved

and lacks the generality and completeness desired in a decision training program.

The Kepner-Tregoe process is an explicit, rational system for gathering and formatting data for decision making and problem solving (Kepner and Tregoe, 1965). It is taught through in-depth workshops which intermingle lectures and a graded series of exercises. The process has four main components: (1) situation appraisal, (2) problem analysis, (3) decision analysis, and (4) potential problem analysis. Proponents of the process claim as advantages that it results in a visible (traceable) process, is streamlined and efficient, forces actions and responses, and helps the decision maker stay on the subject. Furthermore, the requirement to explicitly write out the steps in the analysis of each problem is felt to result in a more conspicuous identification of assumptions and biases than is usually the case in decision analysis. Little data exist with which to evaluate the Kepner-Tregoe process, but its continued commercial success suggests that it is of considerable value in the training of new managerial personnel.

Perceptronics, Inc. has recently developed a decision aiding system specifically intended to facilitate group decisions (Leal and Pearl, 1977). The system is designed to compensate for some of the deficiencies of humans with respect to handling large amounts of data and performing complex calculations. While the decision aiding system is not a training device as such, it allows groups charged with decision making responsibilities to focus on problem exploration and value clarification. Through repeated sessions with the system, it is likely that decision groups will develop more efficient and focussed techniques for problem definition and development of consensus. The system involves interactive elicitation of decision trees, including on-line sensitivity analysis, and multi-attribute analysis of group utility values at criti-

cal points in the tree. An interactive computer system processes group member responses which are entered through a set of response devices. On a large screen, the system displays decision trees, event nodes, and the range of group members' utilities for various outcomes. Initial realization of the system has been in the form of a group decision room which is an instrumented conference room. A trained staff member, termed an "intermediator," manages the general group process and assists with data entry and selection of computer displays. Demonstration studies with the system indicate that it has considerable potential for improving the quality of group decisions as well as for reducing the time taken to arrive at a decision.

2.5.2 Recommendations. Goodman et al. (1976), in the report of a recent conference on the training of decision makers, identify some priorities for improving decision training programs. They suggest that three aspects of the training problem demand immediate attention: training specific skills, evaluating the quality of decisions, and implementing the knowledge obtained through decision research. These three areas are essentially interdependent; however, each entails sufficiently different research strategies to merit distinguishing it from the others.

With respect to training specific skills, Goodman et al. identify several areas of priority. They believe that judgmental biases must be identified and the known biases characterized in terms of underlying cognitive processes. Research is required to determine which biases are amenable to training and which can only be compensated for mechanically so that debiasing or bias-avoiding procedures can be developed where applicable. These problems may be most parsimoniously attacked by looking for common elements in the decision-making strategies used in different tasks. These strategies are the result of basic cognitive processes, so that the interaction between basic cognitive research and cognitive en-

gineering will have to be intensified when straightforward debiasing procedures fail.

Although evaluation is a key element in improving training, it is a weak point in current decision training programs. We do not know how to evaluate most important decisions. Without such knowledge, there is no way of assessing the value of the various training programs now offered or the validity of the claims made for them. It may even be that any simple decision-making procedure, however flimsy its axiomatic basis, is as good as the most sophisticated. The judgmental biases mentioned earlier must also be assessed to determine how much of a difference they make in the optimality of decisions. Some general work on the sensitivity of decisions to bias, must be performed. Goodman et al. (1976) further suggest that ways be developed to help people best assess the quality of their own and their colleagues decisions, and learn from their own experience.

Current understanding and knowledge of decision analysis can be implemented to train decision makers and improve the quality of their performance. For repeatable tasks, the covert decision processes of the expert can be modeled and made explicit in a way that should be quite useful to trainees. In some cases, these models will take the form of algebraic equations. In others, more complex models on the order of sequentially branching computer programs, will be necessary. The potential of judgment modeling for facilitating military and defense decisions is unlimited.

Although Goodman et al. (1976) place emphasis on the training of specific decision skills, they recognize that a common cognitive base may underlie various decision making strategies and that a generalized approach to decision training may have some merit. Nickerson and Feehrer

(1975) similarly advocate an open-minded approach to the question of general as opposed to specific decision training. They feel that an effective decision maker in a variety of situations needs some intellectual appreciation for the decision-making process as it is represented by theoretical treatments of decision making, and some familiarity with certain of the key concepts that decision theorists employ. Such key concepts include a basic introduction to probability theory as well as a working familiarity with notions of rationality, value, utility, mathematical expectation, risk, risk preferences, and so on. Failure to provide an adequate grounding in theory might deprive the decision maker of the sorts of insights that lead to productive use of available decision-aiding techniques.

Kanarick (1969) hypothesizes that decision making can be taught as a skill which should generalize to new situations. With respect to the training of Naval officers, Kanarick comes to the same conclusion as Nickerson and Feeher, namely that training for specific job knowledge may be supplemented by some generalized skill in diagnosis and action selection. In this manner, the specifics of certain tactical situations (e.g., capabilities of ships and weapons, sensors, doctrine, etc.) would be retained, while the skills in decision making are transferred. Kanarick suggests that training decision making as a skill early in an officer's career may provide him with the basic tools necessary to structure subsequent decision problems so that he can analyze them in some relatively consistent and rational manner. To what extent this skill transfers to the operational situation and when in an officer's career this skill should be trained, is a high-priority task for investigation.

With respect to military systems, the development of a generalized approach to decision training would be of particular value. One obvious

advantage would be to facilitate the training of aircrew personnel who transition from one aircraft system to another. Nickerson and Feehrer (1975) suggest that empirical research is needed to determine whether familiarization with theoretical treatments of decision making will in fact improve decision-making behavior. They feel that such training will be efficacious for some people performing certain types of decision tasks but perhaps not for all people or all tasks. One objective of training research should be to identify those conditions under which such training would be effective and those under which it would be a waste of time. Clearly, this is an important issue, but one which will not be resolved until evaluative tools and methods suited to decision making and decision training program evaluation are developed and applied.

2.6 Stress

The concept of stress has been a difficult one to define from a theoretical standpoint (Appley and Trumbull, 1967; Deese, 1962). Nevertheless, investigators concerned with the impact of a variety of psychological and environmental factors on performance both in laboratory and real-world settings generally agree that the introduction of variables commonly recognized as extreme stressors will result in performance decrement or impairment (Berkhout, 1970; Berkun, 1964; Broadbent, 1971).

Prophet (1976, p. 14) points out that "There are few performance environments or situations that produce the task-time press, the general physiological and psychological stress, and bodily-harm threat as does the flight situation..." The aircraft emergency can combine the deleterious physiological effects of a harsh physical environment with the requirement for rapid, complex decision making under conditions of

uncertain information and high personal risk. It would appear that aircraft emergencies are among the ultimate stressors for flying personnel.

The study of decision making under the stress of real life emergency situations has not been easy. Berkun (1964) points out that stress, as it applies to the combat or disaster setting, involves an element of threat or personal risk:

> While stimulus overload, heat, noise and vibration, difficult game decisions, and fine sensory discriminations obviously produce a condition which is frequently and reliably labeled "stressed," there is a basic motivation, drive, or attitude of fear not ordinarily manipulated in human factors research. (p. 22)

It may be that the element of threat or personal risk is the critical factor that underlies the human operator's decision errors that are involved in some aircraft accidents. Wherry and Curran (1966) observe that an operator's reaction to the threat of an impending disaster may well account for more variance in performance among aviators and astronauts than their susceptibility to all the physical and physiological stressors combined. In a similar vein, Zavalova and Ponomarenko (1970), in discussing the responses of pilots to emergency situations, find that

> Human behavior in response to extreme factors may be characterized by: (i) sharp increase in excitability expressed in impulsive acts, impairment and loss of skills or (ii) inhibition and even the cessa-

tion of activity. Both types of reactions result in a disorganization of rational activity on the part of the individual. (p. 11)

Berkun (1964) identifies criteria for studies which are intended to assess the effects of stress on performance. To predict from experimentation the ability of men to cope with real stresses requires, first, a validation of the experimental situation as a substitute criterion for uncontrollable reality. It is argued that the subject must cognitively perceive the situation as stressful, so that he may react realistically and not "as if." Simulation of a stressful environment, then, must avoid cues which invite the subject to deliberately assume a role or which provide him with more psychological support or sustenance than he will receive in the reality to which the findings must generalize. Furthermore, the task he is to perform must be meaningful in the stress-producing context. Stressors which fulfill these requirements ought to produce (1) a measurable disturbance of performance, (2) a report of awareness of a feeling of discomfort, fear, threat, or unpleasantness, and (3) a measurable perturbation of physiological (homeostatic) processes.

Satisfaction of these criteria in a controlled research setting is a formidable accomplishment and, as a result, our knowledge of the effects of stress, as defined by Berkun, on emergency performance, in general, and on decision making, in particular, is mainly limited to anecdotal evidence.

While stress is not well understood, the need remains to prepare aircrews for maximum decision-making effectiveness under emergency conditions. A number of investigators recommend approaches to preparing scenarios for emergency decision making. Bruggink (1978) feels that the

capability both for making immediate responses to crises and for taking slower, more reasoned approaches to problems must be developed. When the unusual occurs, there may be only enough time for an immediate reaction, a response that is governed more by what might be called a sixth sense developed through training and experience, than by the process of reasoning. Additionally, the programming of simulated real-world ordeals should be encouraged. A one-time, unanticipated exposure to incidents such as an iced-up pitot-static system, or total loss of electrical power, would make a pilot more responsive to actual problems in these areas. This type of training promotes enlightened decision making in unusual situations without down-playing the constraints of standard operating procedures.

Zavalova and Ponomarenko (1970) recommend mental rehearsal as a means to improve readiness to respond to an emergency and to cope with its emotional aspects:

> It is known from the psychological literature that the mental representation of motor actions is an active mechanism for forming and perfecting occupational movements. It is important that the imagery reconstruction of an emergency situation be emotionally colored. Then in an actual emergency not only the signals and modus operandi but also the emotional sensations will be "familiar," thereby overcoming the main psychological stress factor in emergencies--surprise. (p. 13)

A frequent theme in recommendations about emergency decision training is that decision makers should be given exposure to, or practice in, execution of disadvantageous decision alternatives as preparation for those situations in which a "bad" choice is better than total disaster. Brug-

gink (1978), for example, recommends that pilots be taught to crash airplanes competently; that is, to develop a working knowledge of crash dynamics and techniques to minimize injury, damage, and fire. Nickerson and Feehrer (1975) review studies which indicate that:

> ...subjects performed less appropriately when operating at a disadvantage than when operating at an advantage. One of the conclusions that Sidorsky and his colleagues drew from the results of a series of studies was that "the inability to analyze and respond appropriately in disadvantageous situations is a major cause of poor performance in tactical decision making." If this observation is generally valid, its implications for tactical decision making are clearly very significant. The implications for training are also apparent, namely, the need for extensive decision-making experience in disadvantageous situations. (p. 159)

In both of these suggestions, there is the implication that decision making breaks down when all alternatives have negative outcomes, but that exposure and training can overcome this impairment.

Our limited understanding of the nature of stress or its effects makes difficult the assessment of various proposals for training to overcome the effects of stress on emergency performance. Bruggink identifies a universal shortcoming in emergency training as "our inability to duplicate the unmitigated stress of a real or imagined threat to survival and its potential effect on individual and team behavior." (1978, p. 5)

Deese (1962, p. 216-217) discusses additional methodological problems associated with designing or evaluating training programs to overcome the effects of stress. Although his discussion deals primarily with

psychomotor performance, it has relevance here. A major conclusion from existing data is that there is no simple relationship between stress and performance. Some experimental evidence led Deese and Lazarus (1952) to hypothesize that the effects of stress would be deleterious early in practice but not so later in practice. This interpretation is equivocal however, because any effects that are the result of practice could be attributed to adaptation. In addition, performance on a task is made up of several components, and stress may affect each differentially. It is impossible to say, generally, what effects will happen early in training compared with late in training, or, indeed, whether or not there will be any differences between early and late practice. Deese (1962) suggests that an appropriate way to look at the problem of stress in training is by means of the transfer paradigm, especially if stress is identified as a stimulus condition. Classical transfer theory leads to the prediction of a decrement when stimulus generalization occurs, an effect obtained by altering the environmental stimuli. Thus, if stress, as a stimulus, is present for either training or performance, but not for both, learning theory would predict a decrement, or poor performance, simply as a result of stimulus generalization. Deese, however, warns against using this concept in attempting to understand the problem of stress and training, because the stimulus character of stress is ambiguous:

> While any stressful stimulus has a stable component that gives rise to the condition of stress, the specific components of such stimuli vary widely in their composition. Thus, the question of stimulus patterning must enter any predictions about the effects of stress made from the point of view of the transfer paradigm. Therefore, it appears that the occasionally stated view that stress should be deliberately introduced during training if it is to be expected during performance is not so sound as it first appears. (pp. 216-217)

Prophet (1976) summarizes the current situation with respect to training for performance under stress as follows:

> It is clear that the USAF pilot must be able to perform reliably and effectively under conditions of severe stress. The manner in which this capability develops and the extent to which it changes as a function of conditions such as non-flying or proficiency flying episodes, age, and career, experience, and personal factors are not known. Because of the criticality of the stress factor to mission performance, force management policies must be based on sound knowledge in this area. Adequate mission performance requires more than just the requisite mechanical skills. Resistance to the disorganizing effects of stress must be sufficient to permit the mechanical skills to operate in effective, integrated fashion. Research is required to this end. (p. 78)

2.7 Summary

The foregoing literature review demonstrates that there is a growing interest in the classification and analysis of decision making skills in a manner that is amenable to training program development. It is further apparent that decision making is an important and complex component of flying skill, but that the acquisition and maintenance of this and related higher order cognitive skills are poorly understood. The limitations humans appear to exhibit as decision makers were reviewed, together with certain suggestions for training programs designed to improve decision performance. A final area of interest, the effect of stress on emergency decision making, was recognized as important, but characterized by severe methodological impediments to those wishing to carry out studies involving stress.

3. AIRCREW EMERGENCY DECISION TRAINING CONFERENCE

3.1 General

One of the key efforts carried out in Year 1 was the convening of a working conference to review the state of the art of aircrew emergency decision training; to consider how current concepts in behavioral decision theory, safety research, and training technology relate to aircrew emergency training; and to identify issues and recommendations for future work. This task was seen as an important step, together with reviewing relevant background literature, in establishing a solid basis for the overall research program.

Approximately seventy individuals participated in the two and one-half day conference which was held in San Francisco in late November of 1978. The participants included representatives of the military support community, military contractors, instructor pilots, and other individuals concerned with aircrew training, safety research, and behavioral decision theory.

3.2 Conference Program

The conference opened with a statement of goals by Major Jack Thorpe of AFOSR. Henry Halff of ONR described the relationship of ONR programs to the emergency decision problem. Next, position papers were given on the application of decision theory to emergency situations by Ward Edwards (USC) and Paul Slovic (Perceptronics, Inc.). A panel session, featuring military pilots and instructors, served to review the emergency training procedures in use by the military services.

Current research efforts aimed at understanding and improving the handling of emergency situations were described by Major Duncan Dieterly (AF HRL); Joseph Saleh, Rosemarie Hopf-Weichel, and Antonio Leal (all of Perceptronics, Inc.); Hubert and Stuart Dreyfus (University of California, Berkeley); and Carl Castore (Purdue and AF HRL/FT, Williams AFB).

James Danaher of the National Transportation Safety Board presented a case study of a commercial aircraft accident that occurred at St. Thomas in 1976, in terms of the decision tasks and decision sequence faced by the pilot. John Lauber and Renwick Curry (NASA-Ames) outlined work in progress to study resource management by commercial aircrews using the full mission simulation technique. They also reported on the work being done at NASA-Ames to study the impact of cockpit automation on performance.

Robert Jacobs (Hughes Aircraft) moderated a panel session in which decision training needs were reviewed from a variety of standpoints: (1) aircraft accident reporting and research (Richard Davis, USC Safety Center), (2) simulator research and training programs (Elizabeth Martin, AF HRL/FT, Williams AFB), (3) instructional systems development (Andy Gibbons, Courseware, Inc.), and (4) procedural doctrine and the precreation of emergency scenarios (Stan Roscoe, University of Illinois).

Current issues and recommendations for future work were identified in small group sessions chaired by Martin Tolcott (ONR), Anchard Zeller (HQ AF Inspection and Safety Center, SEL), and Gary Klein (Klein Associates). Throughout the meeting Tony Modric (Honeywell) served as a reactor to the papers presented, and John Lyman (UCLA) ably summarized the issues raised in his concluding review of the meeting.

The presentations made at the conference were synopsized in a report entitled: Aircrew Emergency Decision Training--A Conference Report which was published as a seperate report under this contract. Some of the key points made and recommendations developed at the meetings are summarized briefly in the following paragraphs.

3.3 Critical Issues

The difficulty of developing a precise and universally accepted definition of an emergency was recognized by all. There was agreement, however, that a number of factors are involved in determining whether a particular aircraft situation would become critical or not. These factors include: crew experience and capability, environmental factors which can ameliorate or complicate a given situation, the nature of the individual malfunction(s) involved, and the degree of accumulation and compounding of malfunctions and performance errors.

Decision making in emergency situations was discussed from a variety of standpoints. Several related continuua were identified which should be considered by those attempting to develop training systems for aircraft emergencies, including:

(1) Problem recognition versus problem diagnosis (also described as template matching versus decision analysis).

(2) Response execution versus response generation, selection and execution.

(3) Standard procedures versus personal decision rules.

Two general schools of thought emerged at the conference, as the above continua suggest--those who emphasized the importance of preplanned emergency situation management and those who emphasized the variability of emergency situations and the need for a flexible, problem-solving approach to emergency responses.

Management skill was identified as a key element in emergency responding, particularly in the multi-person situation. Coordination of crew activities, information sources, and individual decisions within the available time frame and the current mission context fall within the context of resource management, as defined in the full-mission simulation studies conducted at NASA-Ames Research Center. Development of the skills of the command pilot in managing both human and technical resources in an emergency was identified as one clear goal of emergency training programs.

Training programs were discussed from a wide variety of standpoints, including media and methods, sequencing of instruction, the role of the instructor, validation and evaluation of training programs, problems in field implementation, and the variety of audiences which emergency decision training programs are required to address. The role of emergency scenarios in training program development was reviewed and the importance of validating the procedural doctrine to be applied in response to scenarios was stressed. The need for developing scenarios which use realistic cues, information rates and time frames was pointed out. Both prospective and retrospective approaches to scenario generation were viewed as necessary to ensure that a comprehensive and relevant set of training problems be developed.

3.4 Conclusions

Some of the more frequent recommendations and conclusions which were brought forth at the conference include the following:

(1) Performance requirements in aircraft emergency situations range from rote responding to complex analysis.

(2) Emergency decision training should address this range of requirements.

(3) Training at all levels of aicrew proficiency should be considered, not just at initial levels.

(4) Decision theory concepts can be taught to aircrews; however, decision theory must be linked to practical applications to gain acceptance and use.

(5) Areas of importance include: option generation, establishing utilities, personal decision rules, and preplanning/-rehearsal.

(6) Instructional System Development (ISD) personnel should ensure that the systems knowledge necessary for emergency decisions is not omitted from training for specific aircraft systems.

(7) Training should be carried out in a manner that resembles the real life situation (e.g., via scenarios) in order to facilitate transfer.

(8) Ancillary cues should be defined and included in training scenarios/simulations.

(9) Design/development data and field performance data (incidents, accidents) should be fed to ISD personnel to update training regularly.

(10) Special attention should be paid to teaching difficult component skills individually and to developing strategies to deal with persistent performance problems.

It was generally agreed that the conference was successful in meeting its goals. In particular, the meeting served to identify and organize issues and to bring together individuals with related interests. A follow-up conference is proposed for the end of Year 2 or the beginning of Year 3 to bring together a similar group of individuals. The focus of the follow-up conference will be more specific, covering individual research efforts in more depth and addressing selected issues in aircrew emergency decision training which were identified at the 1978 meeting as having high priority.

4. CURRENT APPROACHES TO EMERGENCY TRAINING

4.1 Introduction

With the exception of the past year, the rate of military aircraft accidents has shown a relatively steady decrease over the last twenty years (Nuvolini, 1979). Most of the decrease has been attributed to technological improvements. Accident investigation reports show that human error as a cause, or as a related factor in accidents has remained uniformly high. For example, the National Transportation Safety Board's (NTSB) Annual Review of Aircraft Accident Data for 1977 shows that "pilot" was a factor in 81% of the total accidents, by far the largest percentage of all factors listed. The next highest factor listed was "terrain," which was a contributory cause in only 23% of all accidents. Analogous findings are reported by the United States Air Force. In a study of the primary causes of major aircraft accidents over a ten-year period (1960-1969), Zeller and Thorpe (1971) found that pilot error as a primary cause increased slightly from 39% to 45%, a figure which does not include pilot error as a contributing cause, as the NTSB statistics do. The trend with respect to pilot error has not significantly changed during the current decade, with almost 50% of all U.S.A.F. accidents having pilot error attributed as their primary cause (Zeller, 1978).

During this past year (1978), the overall accident rate in the Armed Forces, which had been steadily decreasing over the past 20 years, has been reversed, showing a slight, but significant and puzzling increase. Nuvolini (1979), writing for "Intercept" magazine, describes a study performed by USAF/IG to determine the "why's" underlying this adverse trend. The report, "Change Pace," which consisted of a detailed analysis of mishap data, an evaluation by the major commands, a review of the analysis, and the publication and distribution of the results,

clearly showed that the increase in the number of destroyed aircraft was due to operational rather than logistical factors. Two causal factors predominated--pilot-induced control losses and controlled flight into the ground. Some of the secondary causal factors identified were pressing, distraction, discipline breakdown, lack of event proficiency, and supervision. Among the recommended actions was the need for better training of pilots, both in terms of quality (realism) and quantity (more flying time). In the present report, issues underlying the problem of developing more realistic training materials for decision making in emergency situations are analyzed.

4.2 Boldface and SET

While a variety of approaches are currently employed in the military to train aircrews for emergency situations, two in particular--Boldface and SET--are of interest because of their differences in approach and in their underlying theoretical bases. A brief review of these approaches follows as a prelude to a consideration of their theoretical underpinnings.

Boldface refers to the large bold print in flight manuals which identifies critical emergency procedures and which must be committed to memory. In the Boldface approach, which has been a standard training method for several decades, training in emergency procedures emphasizes those relatively frequent emergencies to which the pilot must be able to respond immediately without referring to a checklist. Boldface emergencies are those which are so critical that there is no time to refer to the pocket checklist before acting. Typically, Boldface procedures are reviewed thoroughly and frequently. As an example, written paper and pencil tests of the complete set of Boldface procedures may be given once a month to all flight personnel; in addition, the entire set of

Boldface procedures is divided into four sections, and one section is given each week as a mini-Boldface test. Then there are also emergency questions of the day, posted on the flight schedule board, and discussed by all personnel. Altogether, all Boldface procedures may be reviewed at least three times a month. Failure on Boldface tests results in the loss of flight privileges for a given period of time, in general until the testee is qualified on reevaluation. This time period is variable and is at the discretion of the commanding officer. Although passing or failing a Boldface test used to depend on letter-perfect recall of all procedures, the rules have changed to some extent. Some minor errors are occasionally allowed, such as switching steps when the order is not critical to the procedure. Also, some Boldface procedures are occasionally changed, and then sometimes switched back to the original version. Errors on tests reflecting a confusion as to which version is currently in force may also be treated benevolently. All flight personnel participate in these tests, not just student pilots. However, student pilots receive other types of training, both in general procedures and in less critical emergency procedures.

Boldface has been criticized because performance evaluation is by means of paper and pencil tests, but in fact, Boldface procedures are also tested in the simulator, along with other types of less standard emergency responses. Failure to perform the Boldface procedures appropriately in the simulator also results in loss of flight priviliges. Performance on Boldface procedures, then, is evaluated both on tests of verbal recall and by assessing actual behavior in simulators.

A more serious criticism of Boldface has been presented by Thorpe et al. (1976) who point out that Boldface focuses on a disproportionately small part of the pilot's overall task in a given emergency. The ongoing requirement to maintain aircraft control, the need to analyze the full

emergency situation, and the importance of planning ahead for a successful recovery are not part of Boldface. Furthermore, formal Boldface training does not address the need for modification of responses when situational factors make the recommended (Boldface) responses inappropriate.

An additional problem is that Boldface procedures address single malfunctions only, while, in fact, many aircraft mishaps are the result of a complex series of events, any single one of which may not have been sufficient to cause an accident.

These three deficiencies all point to the limited scope of Boldface. In a practical sense, however, the Boldface approach has several advantages. Procedures are clear-cut, easily communicated and evaluated, and once learned, are considered to be highly stress resistant. Among the disadvantages of the Boldface approach is that general decision making skills, such as problem recognition, information seeking, and generation of alternative responses, are ignored in the training program.

The Situational Emergency Training (SET) program (Thorpe et al., 1976) was developed to avoid the conceptual and practical deficiencies of the Boldface approach and it is used as an alternative to Boldface for the training of F-15 pilots at Luke Air Force Base. The scope of SET includes:

(1) Critical and non-critical emergencies.

(2) Consideration of all situational information processing requirements placed on the pilot.

(3) Development of pilot analytic and decision making capabilities which match emergency situation requirements.

SET training emphasizes the use of mission scenarios to systematically present the important situational and psychological variables of aircraft emergencies to students. As an example, at Luke Air Force Base, the general training schedule for new F-15 pilots is divided into two phases. First, during the first two weeks, there is an initial heavy emphasis on lectures which tapers off to one hour a day. Students also have six sessions in the Cockpit Procedures Trainer (CPT) using SET; these sessions, each lasting approximately one hour, orient the student to the simulator and to the airplane. There are also several simulator flights which include a predetermined series of emergencies, along with those added by the instructors as they see fit. Second, after the first two weeks, there is one actual flight and one simulator flight daily. Occasional lectures are also given, and once every two weeks, there is a SET exercise in the CPT. SET scenarios are generated by instructor pilots based on accident reports and problems that occur in the F-15 and then are documented by the Wing Safety Officer. Scenarios are short and represent a mini-incident or problem with three parts:

(1) Brief situation description and presentation of critical events.

(2) List of options (usually four) to select from.

(3) Explanation of why the various options are appropriate or not.

A key aspect of SET is that the student and his instructor interact in a diagnostic fashion around the decision making and response elements of

each mission emergency scenario. In SET, individualized instruction is facilitated through the student-instructor dialog. Transfer to the performance situation is enhanced by the use of a CPT as part of the instructional setting. Simulator training does not provide this interaction, but on the other hand, it supplies more realism by simulating actual flight conditions.

One problem with SET is that the generation of scenarios is time-consuming for the instructor pilots and formal guidelines for scenario generation do not exist. Hence, there is a tendency to limit scenario generation to those cases for which problems have already arisen. This is a practical, but limited approach. The SET library at Luke AFB is fairly small, a fact that suggests the difficulty of developing a large and comprehensive library of training scenarios given the current lack of formal guidelines.

An additional problem with SET, in contrast to Boldface, is performance evaluation. During a CPT session, instructor pilots give feedback but do not formally grade problems. Only simulator sessions are formally graded, but in the simulator, separation of the instructor from the student prohibits direct observation of the student's behavior, and hence, immediate feedback. Grading is subjective, and only based on outcomes, not on ongoing decision-making behavior.

Overall, however, SET represents a more comprehensive approach to emergency training than Boldface, because Boldface only emphasizes the responses that have to be performed when discrete and specifiable malfunctions occur, that is, when the malfunction and its associated cues can be predicted and accurately described. SET, on the other hand, has the following characteristics:

(1) Training focuses on a functionally complete unit, which includes the pilot, the system, ground control, communication, and situational factors such as the weather, time of day, and flight phase.

(2) An attempt is made to simulate the environment adequately, within appropriate constraints, so as to optimize transfer of training. This includes an emphasis on situational details.

(3) SET emphasizes flexibility, where problem structuring, judgment, problem solving, and decision making play a large role, in contrast to the strict adherence to predetermined procedures characteristic of Boldface. Development of discrimination skills is emphasized by including both relevant and irrelevant situational items in the scenarios.

(4) Both student and instructor assume active roles and training/testing sessions are characterized by a fluid exchange of information. The instructor has the option to probe the student's understanding of an emergency situation through the socratic dialog as well as by modifying the parameters of the emergency problem. Rapid evaluation and feedback provide the student with timely reinforcement and knowledge of results.

Although as described above, SET and Boldface appear to represent two antithetical approaches to emergency training, in actuality they complement each other. In practice these two approaches or training philosophies are both in use in some form in all aircrew training programs, although in most programs SET may be used in a relatively informal

fashion. Both approaches are clearly needed for aircrew emergency training. The range of applicability of each to emergency training should be carefully delineated. One way to do this is to examine the cognitive aspects of various emergency decision situations and tasks. By doing so, the performance requirements and related training processes can be isolated and the factors influencing these processes can be identified.

4.3 Theoretical Framework

The theoretical literature concerning the learning processes underlying a given task can provide the connecting link between the desired performance on a task and the training methodology best suited to obtain this desired performance. Alternately, if a training methodology is already in existence, an examination of its theoretical basis may help elucidate the processes it is designed to reinforce, its limitations, and hence its suitability for attaining a given training objective.

In the case of Boldface, which emphasizes the memorization of stimuli and responses, the theoretical orientation best suited to account for the training processes is clearly a combination of operant and classical conditioning. Boldface procedures are acquired via the process of associative learning. In the associative learning paradigm, both the stimuli and the responses are pre-determined, and the only process of interest is the association that is being formed between the stimuli and the responses. Learning is viewed as a relatively passive process, gradually strengthened by association of stimuli and responses through repeated trials. The stronger the association, the more reliable the response--a desirable result in many emergency situations. There is a vast literature on the factors which affect the formation of the association, its resistance to extinction, the effects of interference on for-

getting, the effects of rewards, and the factors influencing stimulus generalization and discrimination. Much is known in these areas that could be profitably applied to ensure that Boldface procedures are optimally learned, but not overemphasized, given their rather narrow focus of applicability.

SET can best be viewed in terms of a cognitive, problem solving approach to learning. Cognitive learning theorists include such concepts as "set," "attention," and "motivation" as determinants of behavior. More importantly, however, the concept of a "schema" as the unit of analysis allows for a much more flexible and comprehensive understanding of memory phenomena than the stimulus-response (S-R) unit, since a "schema" incorporates the influence of previous experiences and of situational factors as contributing elements to both the learning and recall processes.

The concept of reinforcement, central to S-R theories, implies that the environment, rather than the learner, determines the products of learning. Recent changes in instructional technology have been brought about by the cognitive movement in psychology, changes which put more emphasis on the active and constructive role of the learner. According to Wittrock (1978), the cognitive approach leads to the design of

> ...different treatments for different students in different situations to actively induce mental elaborations that relate previous learning and schemata to stimuli. In this conception the learners are active, responsible, and accountable for their role in generative learning. That theme expresses a centrally important part of the cognitive movement in instruction and of the state of the art of instruction.

> ...memory, imagery, and other cognitive processes are now being resurrected in the study of instruction because they are important to the explanation and understanding of human and humane learning. People learn not only by acting and experiencing the consequences of their actions but also by observing others, by imitating models, by watching television, by seeing a demonstration, by discussing issues, even by listening to a lecture; sometimes without practice, without reinforcement, and without overt action. Cognitive elaborations, such as inferences, images, memories and analogies influence their learning and understanding. Learners often construct meaning and create their own reality, rather than responding automatically to the sensory qualities of their environments.

The concept of "schema" makes it possible to account for results of learning experiments that show a discontinuity between the objective inputs of the experiment and the recall performance. For S-R theorists, recall is assumed to be a reproduction of the input, whereas for cognitive theorists, it is a reconstruction, dependent on previous experiences and on situational influences at the time of both input and recall. Most events to be learned (inputs into memory) or general experiences, are assimilated into the schemata and are restructured to "fit the logical and causal conventions characteristic of the individuals' social and intellectual milieu" (Bartlett, 1932). Reconstruction retains the meaning, but not necessarily the exact format, of the input.

These two approaches are not exclusive; both types of learning are possible and can be under the control of the learner. In fact, by varying instructions, Podell (1958) showed that the same material could be learned to fit either an S-R explanation where recall is reproductive, or a cognitive explanation with recall being a reconstruction of the learned material. More recently, Kaufman, Baron, and Kopp (1966) found that instructions "exert powerful controlling influences over rates of

response, influences which far outweighed the influences of the reinforcing contingencies actually present in the operant training condition" (p. 243). The reality of the schedules actually experienced was less influential upon the learners than was the reality described to them in the instructions.

These studies suggest that Boldface and SET can be used side-by-side in a training program and that the main problem is to decide in what situation each is more appropriate. With respect to training for emergency procedures, a study by Zavalova and Ponomarenko (1970) supports the notion that both approaches, SET and Boldface, are needed for optimum performance. These investigators performed a controlled study of pilot behavior involving an induced malfunction during an actual mission. They found that pilots' responses could be easily dichotomized into a first, immediate reaction, and a second, more deliberate response. The first reaction brought the aircraft under control. This appeared to be the equivalent of following a Boldface procedure and was described by the authors as an "unconscious act whose completion did not guarantee the correctness of future actions," but which did reduce "the danger of disrupting the mode of operation right at the beginning." The second type of response involved problem-solving and decision-making processes with the goal of correcting the malfunction. The success in correcting the malfunction and the time needed for it varied widely across individuals. The results of this study suggest that training that includes the development of problem-solving and decision-making skills in realistic settings--an intrinsic characteristic of SET--can considerably improve flight safety.

Current instructional technology follows a behavioristic orientation in the sense that observable events are emphasized in developing training materials. The jobs to be trained for are analyzed, performance objec-

tives are specified, and training materials are developed to conform as closely as possible to the criteria established for acceptable performance. Often, only stimuli and responses that can be objectively described are considered in this scheme. High levels of transfer of training can result, provided the performance environment is clearly delineated, but generalization to other environments may be limited.

It seems that aircrew emergency training which follows a behavioristic orientation can benefit from the theoretical developments of cognitive psychology, just as cognitive psychology expanded the narrow focus of S-R oriented theories in accounting for learning and memory processes. One way to improve such training is to determine which cognitive processes, including decision making and judging, are important in various emergencies and to modify training programs so as to provide for development of these skills in a comprehensive fashion.

5. ACCIDENT REPORT ANALYSIS

5.1 Objective

The purpose of this phase of the current study was to develop an understanding of the types of aircraft accidents which occur in Air Force operations, to determine their relative frequencies of occurrence, and to identify some of the major causes and other factors which contribute to such accidents. This information was sought primarily through a review of USAF aircraft accident reports. Of particular interest was the usefulness of these reports in reaching a better understanding of training needs for emergency procedures.

5.2 Method

5.2.1 Sample. Aircraft accident reports represent a potentially useful source of information about aircraft emergencies. Not all emergency situations result in accidents; conversely, not every accident can be sufficiently documented so as to describe the emergency conditions and events which led up to it. Nevertheless, reports of accident investigations represent the most complete, stable and accessible source of data with respect to emergencies. They are of interest in this study not only as a source of information about emergencies which resulted in an accident, but also as an indirect source of information about emergencies which were successfully resolved.

The United States Air Force requires that all USAF accidents and incidents be investigated by an accident investigation board. There are six categories of reports which are submitted in sequence, from preliminary, through supplemental and progress, to final reports. The results of the investigation are forwarded to commanders of operating echelons, major

commands, support commands, and HQ USAF with complete and detailed information on all pertinent facts relating to the occurrence. The findings may serve as the basis for modification of weapon systems and changes in design criteria, and may be used in operations planning, personnel planning, and other staff actions. Personnel at various Air Force levels review the report, evaluate the contents, and take appropriate action (USAF Accident/Incident Reporting, 1971). The information from the accident/incident reports is classified according to various elements and factors established in a manual which is regularly updated (Aircraft Accident and Incident Classification Elements and Factors, AFISCM 127-1, 1972), and then is indexed and entered into an automated file located at the HQ Air Force Inspection and Safety Center, Norton Air Force Base, California.

Several visits were made to Norton AFB to become familiar with the data bank, report formats, and retrieval procedures.[1] As a result of these visits and a preliminary review of a sample of abstracted reports and other materials, all USAF aircraft accident reports (in abstracted form) for 1977 were selected as a sample. Some 385 reports in total were available which represent all major accidents and all minor accidents with damages of at least $50,000 which occurred in 1977. Because an accident investigation can take several months to be completed and the reports used in this project were obtained in mid-1978, some reports were still subject to being updated. Nevertheless, the reports reviewed represent a fairly accurate overview of the information available, including the type of accident, the phase of operation during which it

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[1] The assistance of Dr. Anchard Zeller in providing an orientation to the USAF Automated Aircraft Accident/Incident Master File is gratefully acknowledged.

occurred, and the conditions under which it occurred, as well as the most likely cause that produced the accident.

The 385 abstracted accident reports selected were each reviewed individually. Similarities and differences among reports were noted and some initial determinations were made about categorization of the information contained in the reports, as described below. Summaries of the detailed review and tabulations of reports in terms of major variables of interest are presented in Section 5.3.

5.2.2 Accident Report Contents. Aside from the headings which classify the accident, each report has two parts, one labeled "Description" and one "Findings." "Description" is a somewhat informal narrative of the events preceding the incident, of the incident itself, and of its consequences. "Findings" is a more structured account in which an attempt is made to attribute one or more basic causes to the incident. Information in the two parts frequently overlaps.

Figure 5-1 shows a typical accident report. Accidents are divided into "Major" and "Minor" depending on the amount of damage and the type of injury incurred. The damage classification is either minor, major, or destroyed, and refers generally to the amount of damage that the aircraft incurred. Injury classification can be of four types: none, minor, major, or fatal. If either the damage or the injury classification is major or greater, the accident is classified as a major accident. For both the injury and the damage classification, the term "missing" is used when the pilot and/or aircraft were not recovered; this is essentially the same as "fatal" and "destroyed," respectively.

MINOR ACCIDENT

DAMG CLAS - MINOR INJ CLAS - NONE
TYPE - COLLAPSE OR RETRACTION OF GEAR
COND- ARRESTING BARRIER
PHASEOPR - LANDING ROLL
BASIC - SHEARED

DESCRIPTION F-4E. ON LANDING AIRCRAFT TOUCHED DOWN APPROXIMATELY 500 FEET DOWN RUNWAY. THE NOSE GEAR STRUT COMPRESSED AND SHEARED. AIRCRAFT FUSELAGE EXTENDED THE BAK-12 BARRIER CABLE. AIRCRAFT CAME TO REST 3800 FEET DOWN THE RUNWAY, 21 FEET LEFT OF CENTERLINE. THE AC SHUT DOWN THE AIRCRAFT AND BOTH CREW MEMBERS PERFORMED EMERGENCY GROUND EGRESS.

FINDINGS F-4E. FINDINGS. (1) THE F-4 FLIGHT MANUAL ADDRESSED HIGH SINK RATES AS THE ONLY SOURCE OF NOSE GEAR OVERSTRESS. (2) PILOT LANDED THE AIRCRAFT WITHIN DESIGN PARAMETERS BUT THE STRESS PLACED ON THE NOSE GEAR EXCEEDED ITS LOAD BEARING CAPABILITY. (3) THE NOSE GEAR STRUT OUTER CYLINDER WAS NOT OF SUFFICIENT STRENGTH TO WITHSTAND NORMAL LANDING LIMITS AND SHEARED BECAUSE OF MATERIEL FAILURE (CAUSE).

FIGURE 5-1.
EXAMPLE OF CONTENTS OF ACCIDENT REPORT

Other classifications for each report include "Type," "Condition," "Phase of Operation," and "Basic Cause." Each may be followed by one or more descriptors, or it may be left blank. (In this study, only the first description entered was utilized in the tabulations and analyses.) One reason for leaving a category blank is that accident reports are entered into the central file in various stages of completion, being updated as more information is obtained, and thus, are in some cases incomplete. In general, the more serious the accident, the more thorough and the longer the investigation, and hence the more updates there will be.

5.3 Analysis

5.3.1 Basic Cause. The category "Basic Cause" refers to the cause of the accident, as reconstructed during the investigation, and is of major interest in the current study, because it points to the antecedents of an emergency situation. It is clear from reading the reports that the assignment of cause is to some extent arbitrary, and that it has not been possible to develop a completely standardized approach for this category. A great deal of subjective evaluation must necessarily enter into this assignment since the cause of an accident has to be inferred from the findings.

For present purposes, only eight categories of basic causes were used, although in the reports reviewed, this number is larger. The eight categories are the following:

(1) Human error. This includes errors attributed to the pilots (operator) as well as other members of the aircrew. (This category is not one of the basic causes listed in the

manual, but was developed for purposes of this study, as explained below.)

(2) FOD and bird strike. By far the largest percentage of mishaps are the result of FOD (foreign object damage). "Bird strike" was included with FOD because they often occur together; i.e., a bird strike causes FOD, and the results, in terms of operational factors, are similar. All FOD and bird strike mishaps were categorized as minor accidents. They are of some interest to us because the cues noted by the aircrew can be the same as for more serious malfunctions. For example, a loud thump or engine vibration could be the result of FOD, but could also be an indication of something more serious.[2] In both cases, the emergency procedures to be followed may be the same. (It should be noted that many FODs are discovered during pre- or post-flight maintenance inspections and the aircrew is never even aware of them at the time of occurrence.)

(3) Improperly connected or installed. This refers to maintenance problems, where some part was either not properly connected or installed, resulting in a malfunction.

(4) Malfunction/Failure. A large number of related causes which were individually listed in the reports were collapsed to form the broader category of "malfunction/failure" and includes "sheared," "materiel failure,"

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[2] FOD can result in serious accidents, but no major accident in 1977 was attributed to FOD.

"stress corrosion," "ruptured/burst," "chafed/frayed," "metal fatigue," "broken/separated," and "defective."

(5) Improper manufacturing/poor quality control. In some cases, defective parts are allowed to be placed in service, resulting in equipment failure.

(6) Inadequate or poor design. This may refer to any number of deficiencies that were not anticipated, such as poorly human factored positioning of switches, or use of unsuitable materials.

(7) "Technical order" in error or inadequate. This refers to errors or inadequacies in the procedures to follow in cases of emergencies.

(8) Other. In this category, subcategories such as "snow/ice," "unsafe surface," etc., were included. In other words, they represent causes attributed primarily to environmental factors. In general, these factors contribute to accidents, rather than causing them, but in a few cases, they were listed as the primary cause.

Two other basic causes should be mentioned here. The first is "dropped object." This is listed as a basic cause in several reports of mishaps, but from reading the "description" and "findings" it was clear that the dropped object was often the result of improper installation, or of some other malfunction. For this reason, those accidents which had "dropped object" as a basic cause, were included in either category 3 or 4, as appropriate.

A second basic cause often used was "compressor stall;" as above, this cause was the result of some other problem, rather than itself being a basic cause, and the original cause could usually be discovered by reading the description. Hence accidents which showed it as a basic cause were included in a more appropriate category.

In many reports, no basic cause was identified. However, a close reading of the description and findings would indicate that one of the eight basic causes could be assigned, most frequently human error. As noted above, human error is not a "basic cause" used by USAF coders at the Norton Flight Safety Center but was included in this review in order to identify accidents in which human factors were involved. One such report in which "human error" was assigned as a cause after review is shown in the example of Figure 5-2. "Basic" (i.e., basic cause) is left blank, but under "Findings," finding 2 attributes the cause to "operations factor, operator": "The pilot attempted an unauthorized low altitude rolling crossover maneuver while in a heavy gross weight/AFT CG condition to change wing position on the lead aircraft, and the aircraft stalled and departed controlled flight." It is clear that the pilot made an error, and thus caused an accident. The information which is <u>not</u> contained in the report is why the error was committed. In all, 46 reports of major accidents which had no basic cause assigned could be classified as due to human error and these are included in the data that follow.

Figure 5-3 represents a summary of the frequencies of occurrence of basic causes for the 87 major and the 298 minor accidents in 1977, tabulated according to the eight basic causes described above. Overall, human error accounted for about 1 in 5 accidents; however, when major accidents are considered alone, slightly more than 1 in 2 major accidents are ascribed to human error. Certain causes appear to be more likely to

MAJOR ACCIDENT

DAMG CLAS - DESTROYED   INJ CLAS - NONE
TYPE - SPIN OR STALL
TYPE - ABANDONED AIRCRAFT
COND -
PHASEOPR - LOW LEVEL FLIGHT
BASIC -

DESCRIPTION RF-4C. THE MISHAP AIRCRAFT WAS NUMBER 4 IN A FOUR-SHIP FLIGHT RETURNING TO HOME BASE. THE MISSION WAS BRIEFED TO INCLUDE LOW ALTITUDE VISUAL RECONNAISSANCE. WHILE PROCEEDING EN ROUTE, THE FLIGHT ASSUMED TACTICAL FORMATION. IN THE VICINITY OF THE SECOND PLANNED TARGET, WITH THE MISHAP AIRCRAFT ON THE ELEMENT LEAD'S LEFT WING, THE ELEMENT LEAD ENTERED A SLOW LEFT TURN. THE PILOT OF THE MISHAP AIRCRAFT ATTEMPTED TO CONTROL THIS OVERTAKE BY USING A ROLLING MANEUVER TO CROSS OVER TO THE ELEMENT LEAD'S RIGHT WING. DURING THE MANEUVERS, THE AIRCRAFT DEPARTED CONTROLLED FLIGHT. THE WSO INITIATED A SUCCESSFUL DUAL-SEQUENCED EJECTION AT ABOUT 3,600 FEET AGL. THE AIRCRAFT WAS DESTROYED UPON IMPACT WITH THE TERRAIN.

FINDINGS RF-4C. FINDING 1. THE MISHAP AIRCRAFT CONFIGURATION PLACED THE AIRCRAFT LONGITUDINAL STABILITY IN AN AREA DEFINED BY THE FLIGHT MANUAL AS BEING MINIMALLY ACCEPTABLE AND REQUIRING SMOOTH POSITIVE CONTROL INPUTS. FINDING 2. CAUSE. OPERATIONS FACTOR, OPERATOR. THE PILOT ATTEMPTED AN UNAUTHORIZED LOW ALTITUDE ROLLING CROSSOVER MANEUVER WHILE IN A HEAVY GROSS WEIGHT/AFT CG CONDITION TO CHANGE WING POSITION ON THE LEAD AIRCRAFT, AND THE AIRCRAFT STALLED AND DEPARTED CONTROLLED FLIGHT. FINDING 3. THE CREW MEMBERS EJECTED, SUSTAINING NO SIGNIFICANT INJURIES: THE AIRCRAFT WAS DESTROYED UPON GROUND IMPACT.

FIGURE 5-2.
EXAMPLE OF REPORT OF ACCIDENT INVOLVING HUMAN ERROR

CAUSE	MAJOR	MINOR	TOTAL
"Human Error"	46 (52.87)[1]	27 (9.06)[2]	73 (18.96)[3]
FOD/Birdstrike		148 (49.66)	148 (38.44)
Malfunction/Fail	19 (21.84)	71 (23.83)	90 (23.38)
Improper Connection/Installation	4 (4.6)	23 (7.72)	27 (7.01)
T.O. in Error or Inadequate	7 (8.05)	11 (3.69)	18 (4.68)
Inadequate/Poor Design	7 (8.05)	6 (2.01)	13 (3.38)
Improper Mfg/Poor Q.C.	3 (3.45)	4 (1.34)	7 (1.82)
Other	1 (1.15)	8 (2.68)	9 (2.34)
Total	87 (100%)	298 (100%)	385 (100%)

[1] Percentage of all major mishaps.
[2] Percentage of all minor mishaps.
[3] Percentage of all mishaps.

FIGURE 5-3.
1977 AIR FORCE ACCIDENTS CATEGORIZED BY BASIC CAUSE

result in major accidents than minor accidents. These include inadequate/poor design, in addition to human error. Causes which are apparently more likely to result in minor accidents than major accidents include FOD/birdstrike, malfunction/failure, improper connection/ installation, and technical order in error.

Figure 5-4 breaks down the 87 major accidents by damage class and injury class. Slightly over 60% (52 of 87) of these accidents resulted in death or major injury, and 41% (36 of 87) resulted in both death and loss of aircraft. Human error accounted for 46 of these 87 major accidents, as Figure 5-3 shows. Further analysis, not shown in Figures 5-3 and 5-4, revealed that human error could be identified as a cause in 82% (31 of 38) of the fatalities that occurred, in 54% (41 of 76) of the incidents in which aircraft were lost, and 81% (29 of 36) of the incidents in which aircraft and lives were both lost.

Of the accidents in which aircraft were destroyed, but no injuries occurred, only 19% (4 of 21) were attributed to human error, and of those in which no fatalities occurred, only 38% (15 of 40) were attributed to human error. The higher survival rate in accidents attributed to causes other than human error may mean that system-induced emergency situations can be diagnosed and evaluated more easily than other types of critical situations; in the former, there is time to make the decision to eject, whereas in the latter, human error often coincides with the departure from the boundaries of the performance envelopes, and the decision to eject is made too late.

5.3.2 Phase of Operation. Figure 5-5 presents a summary of the number of major accidents that occurred in 1977 by phase of operation. The categories employed correspond to those used in the classification manual with the exception that a few have been collapsed into larger

DAMAGE CLASS	INJURY CLASS	NUMBER	PERCENTAGE
Destroyed	Fatal	33	37.93
Destroyed Missing	Missing (presumed dead)	3	3.45
Destroyed	Major	13	14.94
Destroyed	Minor	6	6.90
Destroyed	None (pilots parachuted safely)	21	24.14
None	Fatal (parachute accidents)	2	2.30
Major	Major	1	1.15
Major	None or Minor	8	9.20
		87	100%

FIGURE 5-4.
MAJOR ACCIDENTS CATEGORIZED BY DAMAGE AND INJURY CLASSIFICATION

PHASE OF OPERATION	NUMBER
Engines running, not taxiing	3
Takeoff roll	1
Initial climb	6
Prolonged climb	3
Inflight normal; inflight other	21
Inflight aerobatics	7
Inflight refueling	1
Air-to-air ordnance delivery	6
Air-to-ground ordnance delivery	13
Low-level flight	11
Descent; Flare-out	3
Landing approach; Landing other	5
Unpremeditated go-around	1
Landing roll	5
No phase assigned	2
	87

FIGURE 5-5.
NUMBER OF MAJOR ACCIDENTS ACCORDING TO PHASE OF OPERATION

groupings (e.g., inflight normal and inflight other). Figure 5-5 is not particularly revealing. Some 22% (19 of 87) occurred during ordnance delivery, 24% (21 of 87) occurred in normal or "other" inflight conditions, and 13% (11 of 87) in low level flight. Additional tabulations of major accidents according to phase of operation by type or by condition were not found to be of interest and are not shown here.

5.3.3 Type of Accident. Over the years, descriptors for type have been selected that seemed best to describe an accident; new types were included as needed, and perhaps old types simply not used anymore (Zeller, 1978). The assignment of a descriptor for type may apply at a variety of points in the sequence of events which make up an accident, as exemplified by the following three types: "spin or stall," "collision," and "abandon aircraft." "Spin or stall" can be characterized as a cause or as the beginning of an emergency situation; "collision" is a result, and "abandon aircraft" is an action taken following an emergency situation. Thus, "type" is not always a useful classification for present purposes of identifying emergency situations and associated training needs, especially with respect to major accidents.

For purposes of illustration, major and minor accidents are shown in Figure 5-6, categorized according to type of accident. Nineteen different types of accidents are provided in the manual for abstracting accident reports. Only 15 were actually employed in 1977 as shown in Figure 5-6.

By far the greatest proportion of major accidents, 34% (30 of 87) are of the type "collision with ground or water," which reflects an outcome of an emergency situation, rather than a type that would be descriptive of an emergency situation. The same is true of the second most frequent type, "abandon aircraft" (21%, or 18 of 87). The third most frequent

TYPE	MAJOR	MINOR
1. Fire/Explosion in the air	17	21
2. Fire/Explosion on ground	2	9
3. Aircraft collision in air	2	4
4. Collision with ground or water	30	2
5. Abandon aircraft	18	-
6. Other Collision	3	41
7. Spin or Stall	4	-
8. Hard Landing	1	2
9. Wheels-up Landing	1	4
10. Airframe Failure	1	5
11. Collapse or Retraction of Gear	3	7
12. Loss of Directional Control	-	1
13. Loss of Directional Control (ground)	3	10
14. Equipment jettisoned inadvertently	-	8
15. Loss of aircraft structure or equipment	-	20
16. No type assigned	2	164
	87	298

FIGURE 5-6.
COMPARISON OF MAJOR AND MINOR ACCIDENTS BY TYPE

type, "fire/explosion in the air" (20% or 17 of 87), does represent an emergency situation. Of those, 71% (12 of 17) have "abandon aircraft" as a secondary type.

A large proportion of minor mishaps, 55% (164 of 298) have no type assigned. One reason is that they are not usually investigated very thoroughly, and unless the "type" is obvious from the beginning, it is simply left blank. Another reason mentioned earlier is that investigations take time and the reports are not necessarily complete when received, although this is more often the case for major accidents than for minor accidents.

As can be seen from Figure 5-6, the type "fire/explosion in the air" was relatively frequent for major as well as for minor accidents. For this reason, the reports of those 38 accidents were examined in some detail with the idea of discovering some major differences in the sequence of events leading to a major accident compared to that of a minor accident. Little information was found in the accident reports reviewed to suggest that differences in events and aircrew responses occurred. One possible reason for this may be that most accidents of the type "fire/explosion in the air" are caused by a malfunction of some sort and that aircrew actions in response to such a situation are carefully prescribed by the Boldface procedures.

5.4 Discussion

The sample of USAF accident reports reviewed clearly supports the widely-held belief that approximately half of the serious aircraft accidents which occur are the result of human error. Furthermore, it appears that human error is more likely to be associated with a major

accident than a minor accident if it is identified at all as a basic cause of an accident.

Tabulations of accidents by phase of operation and type of accident were not particularly revealing. They do point to the variety of accidents that can occur and, when these descriptive categories are combined with basic cause, they can be helpful in identifying areas of training need.

Accident reports are typically very thorough, particularly for major accidents. The fundamental purpose of accident investigation is "to determine the facts, conditions, and circumstances pertaining to the accident with a view to establishing the probable cause thereof, so that appropriate steps may be taken to prevent a recurrence of the accident and the factors which led to it" (ICAO, 1970). It has frequently been observed that assignment of basic cause is a difficult task in accident investigation. Perhaps one of the more valuable results of reviewing a series of accident reports is an appreciation for the complex chain of events which often underlies an accident. This is particularly true for accidents involving human error and human factors in general. Often, the basic causes assigned to an accident are, in fact, symptoms, in contrast to root causes, a concept of considerable interest and importance. According to Parker (1978) for example, virtually all of today's aircraft accidents occur as a result of a repeated cause. Technical deficiencies, when discovered, can be corrected rather easily, but most of the repeat causes include human factors related deficiencies. These are more difficult to correct, because these repeat causes are not usually root causes. For example, one of the most common and serious repeat cause factors is flying in adverse weather conditions; it is quite obvious that this is not a root cause. A root cause has to answer the question "Why?"

Peterson (1975) defines root causes as "those which would effect permanent results when corrected," but the definition should include a statement concerning the availability of the means for correcting the root cause. How does one correct "flying in adverse weather conditions"? The problem of identifying the "root cause" is necessarily very complex. There are always antecedents to each identified cause. For example, if a heart attack is suspected as a cause factor, the root cause may have been a deliberate disregard of medical regulations. That in itself may have been the result of inadequate indoctrination concerning the seriousness of concealing a disability. The determination of root causes, when related to human behavior, is obviously difficult.

With respect to emergency procedures, a pragmatic approach may be the most useful, namely to single out those cause factors which have the capacity of being manipulated during training. In this regard, the material available in accident reports is useful because it helps in generating hypotheses concerning which behavioral elements appear important and need a greater emphasis during training. However, the review of accident reports is not sufficient in itself to clearly identify performance problems or training needs. Additional detail is required to identify the events and decisions which are involved in or contribute to accidents.

One source of this type of information consists of direct interviews with aircrew members who have experienced emergencies. If the interviews are conducted relatively soon after the incident, a great deal of information can be obtained directly from the aircrew, not only with respect to what actually happened, but also concerning their thoughts as they were trying to deal with the emergency situation. One such interview is summarized as a case study in Appendix A, entitled "30 Minutes Over Florida. " The overall emergency faced by the pilot (and his stu-

dent pilot) in an S-3 training flight is broken down in Figure A-1 into a series of events and decisions which occurred from the onset of the emergency to its successful resolution. As Figure A-1 suggests, at several points in the overall series of events, the incident could have culminated in an accident, but did not.

In summary, accident reports are a useful source of data regarding the settings and factors which are associated with aircraft accidents. To the extent that human error can be associated with such accidents, it should be possible to identify improvements in aircrew training programs which would help to avoid or ameliorate the outcomes of such emergencies. Accident reports, themselves, can assist in identifying problem areas which may be resolvable through improved training programs. Additional information is clearly needed, however, to identify the specific performance problems and human errors involved at a level of detail which can be addressed through training.

6. PRELIMINARY CLASSIFICATION OF EMERGENCY SITUATIONS

6.1 Objective

The objective of this phase of activity was to identify a set of representative aircraft emergency situations and classify them in terms of certain attributes and underlying decision components. The intent was to provide an overview of the types of malfunctions that need to be considered when developing training materials and scenarios for emergency decision training programs.

6.2 Method

The information reported in this chapter is the result of interviews carried out during site visits to military bases and installations in Southern California and Arizona. Altogether, 18 pilots with varying backgrounds and experience levels were used as sources of expert knowledge and opinion. They included two senior pilots from the Office of Naval Research in Pasadena, one F-16 test pilot from Edwards Air Force Base, four F-15 instructor pilots from Luke Air Force Base, and eleven F-14 fighter pilots from Miramar Naval Air Station.

The interviews always began with an explanation of the reasons and goals of the present study, followed by a brief statement concerning the rationale for decision training and a definition of appropriate terms. As necessary, pilots were given examples of decision components, decision parameters, and attributes of malfunctions to orient them to specific tasks. In general, pilots were asked to consider only that aircraft system with which they were the most familiar when responding to specific questions or completing exercises.

Data-gathering efforts were broken down into four stages, and methodological details of each are reported separately in the following sections of this chapter.

6.3 Matrix of Emergency Situations

Listings of emergency procedures were collected from the training manuals for several current aircraft systems. These listings were shown to two experienced pilots who worked together on this task. They were instructed as follows:

> Please select those situations that you consider particularly important, that require decision-making, that appear complex, and for which current training methods do not seem optimal to you. In addition, if you can think of situations that are not listed, please add them to the list.

It became apparent that the listings of emergency situations from flight manuals were not sufficient in themselves to allow the pilots to characterize the situations as requested. Flight phase was found to be necessary in order to assess the importance of an emergency condition. As a result, the pilots selected 41 emergency conditions (malfunctions) and 9 flight phases. Figure 6-1 depicts the 369-cell matrix formed when the 41 emergency conditions are crossed with the flight phases. The emergency conditions and most flight phases are self-explanatory. The three takeoff conditions are: (1) initial takeoff--taxi to about 110 knots, (2) intermediate takeoff--110 knots to lift-off, and (3) final takeoff--after lift-off. It should be noted that not all cells of the matrix are meaningful since some malfunctions already specify flight phase (e.g., drag chute deployed inflight), and others are not emergencies during

APPROACH/LANDING	HI/FAST	HI/SLOW	LOW/FAST	INFLIGHT LOW/SLOW	FINAL	INTENDED	TAKE OFF INITIAL	GROUND OPERATIONS	FLIGHT PHASE / EMERGENCY CONDITION
									THRUST LOSS - A/B
									THRUST LOSS - PARTIAL
									THRUST LOSS - TOTAL
									STALL STAGNATION
									NOZZLE FAILURE
									OIL PRESSURE MALFUNCTION
									STUCK THROTTLE
									FIRE ON START
									ENGINE FIRE
									LANDING GEAR FAILS TO RETRACT
									LANDING GEAR FAILS TO EXTEND
									BRAKE MALFUNCTION
									MAIN TIRE FAILURE
									NOSE TIRE FAILURE
									NOSEWHEEL STEERING MALFUNCTION
									GROUND SAFETY SWITCH MALFUNCTION
									ELECTRICAL MALFUNCTION - BATTERY
									ELECTRICAL MALFUNCTION - DC POWER
									MAIN GENERATOR FAILURE
									EMERGENCY GENERATOR FAILURE
									TOTAL GENERATOR FAILURE
									HYDRAULIC SYSTEM FAILURE - SYST A
									HYDRAULIC SYSTEM FAILURE - SYST B
									DUAL HYDRAULIC SYSTEM FAILURE
									PTO SHAFT FAILURE
									FUEL SYSTEM MALF - FORWARD OR AFT LOW
									FUEL SYSTEM MALF - BAD DISTRIBUTION
									AIR CONDITIONING MALFUNCTION - HIGH TEMP
									LOSS OF CABIN PRESSURE
									LOW OXYGEN
									SMOKE OR FUMES IN COCKPIT ELECTRICAL FIRE
									OVER HEAT CAUTION LIGHT ON
									INS - COMPUTER FAILURE
									INS - PLATFORM FAILURE
									FLIGHT CONTROL SYSTEM MALFUNCTION - ADC
									FLT CTRL SYST MALF - LEADING EDGE FLAP
									FLT CTRL SYST MALF - RUNAWAY TRIM
									CANOPY LOSS
									DRAG CHUTE DEPLOYED IN FLIGHT
									STALL OR DEPARTURE FROM CONTROLLED FLIGHT
									SPIN

FIGURE 6-1.
MATRIX OF EMERGENCY CONDITIONS BY FLIGHT PHASES

during certain flight phases (e.g., brake malfunctions or tire failure inflight).

6.4 Selection of Emergency Situations

Three experienced pilots were shown the matrix of emergency situations and were asked to assign a rating to each cell for safety criticality and for time criticality. The rating scales used are shown in Figure 6-2. Safety criticality was defined as the criticality of the potential outcome, and the ratings correspond to the classifications used by the U.S. Air Force in reporting accidents and incidents. Time criticality refers to the amount of decision time available when an emergency condition is recognized, and the pilots suggested three ratings: short, long-self, and long-assisted. "Short" means that time criticality is high, and "long" that it is low. The distinction between "long-self" and "long-assisted" simply refers to the availability of assistance in making a decision with respect to the particular emergency.

Figure 6-3 presents the results of the rating procedure carried out by the three experts. The cells marked with an "X" represent the 67 combinations of malfunction and flight phase which were judged to be the most critical emergency situations in terms of safety criticality (i.e., were assigned ratings of 1 or 2). Combinations for which there was no consensus, or no rating was assigned, were eliminated at this stage from further consideration. Time criticality ratings were not used because it seemed important to include high and low time-critical situations in the final selection.

The 67 malfunction/flight phase combinations represent critical situations following which the aircraft could become damaged beyond economical repair and lives might be lost. They are not necessarily complex

"FINAL OUTCOME" (SAFETY CRITICALITY)

1 = aircraft and crew loss

2 = aircraft loss

3 = major damage

4 = minor damage

5 = no damage

"PROCESS TIME" (TIME CRITICALITY)

1 = short

2 = long-self

3 = long-assisted

FIGURE 6-2.
RATINGS USED FOR FINAL OUTCOME AND PROCESS TIME

EMERGENCY CONDITION / FLIGHT PHASE	APPROACH/LANDING	HI/FAST	HI/SLOW	LOW/FAST	INFLIGHT LOW/SLOW	FINAL	INTERMED	TAKE OFF INITIAL	GROUND OPERATIONS
THRUST LOSS A/B									
THRUST LOSS PARTIAL									
THRUST LOSS TOTAL	X	X	X	X	X	X	X	X	
STALL STAGNATION	X	X	X	X	X	X			
NOZZLE FAILURE						X	X		
OIL PRESSURE MALFUNCTION		X					X		
STUCK THROTTLE		X					X		
FIRE ON START									
ENGINE FIRE	X	X	X	X	X	X	X	X	
LANDING GEAR FAILS TO RETRACT									
LANDING GEAR FAILS TO EXTEND									
BRAKE MALFUNCTION	X								
MAIN TIRE FAILURE									
NOSE TIRE FAILURE									
NOSEWHEEL STEERING MALFUNCTION									
GROUND SAFETY SWITCH MALFUNCTION									
ELECTRICAL MALFUNCTION - BATTERY									
ELECTRICAL MALFUNCTION - DC POWER									
MAIN GENERATOR FAILURE		X	X	X	X				
EMERGENCY GENERATOR FAILURE									
TOTAL GENERATOR FAILURE									
HYDRAULIC SYSTEM FAILURE - SYST A									
HYDRAULIC SYSTEM FAILURE - SYST B									
TOTAL HYDRAULIC SYSTEM FAILURE									
PTO SHAFT FAILURE									
FUEL SYSTEM MALF - FORWARD OR AFT CG		X	X						
FUEL SYSTEM MALF - BAD DISTRIBUTION		X		X					
AIR CONDITIONING MALFUNCTION - HIGH TEMP									
LOSS OF CABIN PRESSURE									
LOW OXYGEN		X	X						
SMOKE OR FUMES IN COCKPIT ELECTRICAL FIRE									
OVER-HEAT CAUTION LIGHT ON									
INS - COMPUTER FAILURE									
INS - PLATFORM FAILURE		X	X	X	X	X			
FLIGHT CONTROL SYSTEM MALFUNCTION - [illegible]		X	X	X	X	X			
FLT CTRL SYST MALF - LEADING EDGE FLAP	X					X			
FLT CTRL SYST MALF - RUNAWAY TRIM									
CANOPY LOSS		X	X	X					
DRAG CHUTE DEPLOYED IN FLIGHT	X				X				
STALL OR DEPARTURE FROM CONTROLLED FLIGHT	X	X	X	X	X	X			
SPIN	X	X	X	X	X	X			

FIGURE 6-3.
EMERGENCY SITUATIONS RATED AS SAFETY CRITICAL

decision situations, since, in many cases, actions to be taken upon perception of a malfunction are dictated by Boldface procedures and do not require involved analysis or selection from among alternatives. In general, a malfunction during ground operations or initial takeoff was not considered by the experts to lead to loss of aircraft or aircrew.

Other general findings had to do with the relationship between time and safety criticality. In general, time criticality was rated high for any emergency that occurs during takeoff or landing and that also was rated as having high safety criticality. Situations were also rated as high in time criticality if they involved low altitude and were rated as high in safety criticality. Conversely, for high altitude situations, even if the situation had a high safety criticality rating, low ratings of time criticality were given, apparently because the experts felt that decision time is generally greater at higher altitudes.

6.5 Attributes of Emergency Situations

Once the set of emergency situations was pared down to manageable proportions, a somewhat more rigorous analysis was possible. First, descriptions of the 67 selected situations were individually typed on 4x6 cards. Then, seven pilots were asked to rank order the cards according to safety criticality, time criticality, and current decision-making effectiveness. For safety criticality, the pilots were asked to rank situations in terms of how dangerous each was; for time criticality, the ranking factor was how much time they had to evaluate the situation and take action; and for current decision-making effectiveness, they were asked to consider how well they were trained to deal with each situation and how effective they felt their decisions would be if they were faced with it. The set of cards was ordered twice by each pilot,

once each on two of the three attributes. Each pilot received a different combination and order of attributes.

Each situation was assigned a score which was the average of the ranks assigned by the pilots. Since the pilots did not always agree on how to rank the situations, an agreement score was calculated which was the mean difference between the raw rank scores. The scores are shown in Figure 6-4. All 67 situations are listed in Figure 6-4, but in some cases no scores are available. This is because the pilots had the option to exclude situations that were not relevant to their experiences and they did so in several cases.

High scores represent high time and safety criticality, and low decision-making effectiveness. Although statistical measures of association were not computed because relatively few data points were obtained, there appears to be some positive correlation among the three attributes. In general, situations that have a high safety criticality were also those for which the rankings suggest that there is little time to make decisions and that current decision-making effectiveness is low.

The distributions of mean ranks for each attribute are shown in Figure 6-5. The distributions for safety criticality and time criticality reveal a broad distribution of scores and suggest that the pilots were able to discriminate well among the situations. The distribution for decision-making effectiveness is bunched and suggests that the pilots did not see much distinction among various situations with respect to this attribute.

Figure 6-6 presents the distributions of agreement scores for the ranks produced for each attribute. The lower the score, the better the agreement on the rankings. Inspection of Figure 6-6 reveals that there was

(MALFUNCTION X FLIGHT PHASE)	SAFETY CRITICALITY[1] MEAN RANK	SAFETY CRITICALITY[1] AGREEMENT SCORE	TIME CRITICALITY[1] MEAN RANK	TIME CRITICALITY[1] AGREEMENT SCORE	DECISION-MAKING[2] EFFECTIVENESS MEAN RANK	DECISION-MAKING[2] EFFECTIVENESS AGREEMENT SCORE
1 Total Engine Failure (IT)	27.5	3	31	36	29	36
2 Total Engine Failure (IM)	32	4	55.5	5	39.8	41
3 Total Engine Failure (FT)	47.5	9	62.5	7	40.8	38
4 Total Engine Failure (FLS)	54.5	5	51	6	44	35
5 Total Engine Failure (FLF)	49	2	47.5	5	43	39
6 Total Engine Failure (FHS)	42.5	5	41	0	48	19
7 Total Engine Failure (FHF)	42.5	7	38	2	48	21
8 Total Engine Failure (AL)	55	8	64.5	5	47	42
9 Stall/Stagnation (FT)	43	16	53	10	31.3	57
10 Stall/Stagnation (FLS)	44	24	46.5	1	32.8	44
11 Stall/Stagnation (FLF)	39	17	44.5	1	37.5	40
12 Stall/Stagnation (FHS)	13.5	9	41.5	3	27	38
13 Stall/Stagnation (FHF)	13.5	7	39	6	26.5	38
14 Stall/Stagnation (AL)	47	22	54	14	34.5	59
15 Nozzle Failure (FT)	42	16	39	24	46.3	54
16 Nozzle Failure (FLS)	41	16	34	20	45.8	42
17 Oil Pressure Malfunction (FT)	23.5	23	12	2	25	25
18 Oil Pressure Malfunction (FHF)	22.5	27	6.5	7	41.3	44
19 Stuck Throttle (FT)	19.5	13	21	2	29.8	39
20 Stuck Throttle (FHF)	14	0	18.5	9	39.3	36
21 Engine Fire (IT)	32	10	23	22	31.8	27
22 Engine Fire (IM)	33	10	51.5	1	46.8	14
23 Engine Fire (FT)	38.5	1	57.5	5	39.8	47
24 Engine Fire (FLS)	45.5	5	36.5	5	35.5	19
25 Engine Fire (FLF)	43	2	34.5	9	34.8	17

[1]High ranks represent high criticality.

[2]High ranks represent low decision-making effectiveness.

FIGURE 6-4.
MEAN RANKS AND AGREEMENT SCORES FOR EMERGENCY SITUATION ATTRIBUTES

(MALFUNCTION X FLIGHT PHASE)	SAFETY CRITICALITY[1] MEAN RANK	SAFETY CRITICALITY[1] AGREEMENT SCORE	TIME CRITICALITY[1] MEAN RANK	TIME CRITICALITY[1] AGREEMENT SCORE	DECISION-MAKING[2] EFFECTIVENESS MEAN RANK	DECISION-MAKING[2] EFFECTIVENESS AGREEMENT SCORE
26 Engine Fire (FHS)	29.5	21	31	14	39.3	21
27 Engine Fire (FHF)	30.5	21	33.5	3	39	21
28 Engine Fire (AL)	40.5	7	58	2	40.8	53
29 Brake Malfunction (AL)	21.5	17	6.5	3	33	49
30 Total Electrical Failure (FLS)	15.5	19	15	6	37	42
31 Total Electrical Failure (FLF)	14.5	19	15	8	34	37
32 Total Electrical Failure (FHS)	13.5	19	14.5	11	42.5	43
33 Total Electrical Failure (FHF)	12.5	19	15.5	11	42.8	41
34 Fuel Malfunction (FLF)	7.5	1	23	34	32.3	46
35 Fuel Malfunction (FHF)	7.5	1	23.5	29	34.8	48
36 Fuel, Low Pressure (FHS)	6.5	7	6	2	30.3	48
37 Fuel, Low Pressure (FHF)	7.5	7	6	4	31	48
38 Low Oxygen (FHS)	2	9	5	4	26.5	56
39 Low Oxygen (FHF)	1	0	5	2	27.3	56
40 IFR: Instrument Failure (Plat) (FT)						
41 IFR: Instrument Failure (Plat) (FLS)						
42 IFR: Instrument Failure (Plat) (FLF)						
43 IFR: Instrument Failure (Plat) (FHS)						
44 IFR: Instrument Failure (Plat) (FHF)						
45 Flight Control - ADC (FT)	44.5	23				
46 Flight Control - ADC (FLS)	43.5	23				
47 Flight Control - ADC (FLF)	40	18				
48 Flight Control - ADC (FHS)	17	2				
49 Flight Control - ADC (FHF)	16	2				

[1]High ranks represent high criticality.
[2]High ranks represent low decision-making effectiveness.

FIGURE 6-4. (CONTINUED)
MEAN RANKS AND AGREEMENT SCORES FOR EMERGENCY SITUATION ATTRIBUTES

(MALFUNCTION X FLIGHT PHASE)	SAFETY CRITICALITY[1]		TIME CRITICALITY[1]		DECISION-MAKING EFFECTIVENESS[2]	
	MEAN RANK	AGREEMENT SCORE	MEAN RANK	AGREEMENT SCORE	MEAN RANK	AGREEMENT SCORE
50 Flight Control - Lead Flap (FT)	26.5	41	38	32	30.3	36
51 Flight Control - Lead Flap (AL)	25.5	41	35	28	29.5	30
52 Canopy Loss (FLF)	21.5	3	32.5	9	29.8	6
53 Canopy Loss (FHS)	20	2	31	8	27.8	8
54 Canopy Loss (FHF)	21.5	1	33.5	5	27.8	9
55 Drag Chute in Flight (FLS)			1	0		
56 Drag Chute in Flight (AL)			2	0		
57 Stall/Departure (FT)	62	4	56.5	1	33.5	56
58 Stall/Departure (FLS)	58.5	3	44	22	32	24
59 Stall/Departure (FLF)	59.5	3	42.5	21	32.3	22
60 Stall/Departure (FHS)	18	12	26	0	26	14
61 Stall/Departure (FHF)	18	14	38.5	27	25.3	14
62 Stall/Departure (AL)	62	6	58	4	35	58
63 Spin Recovery (FLS)	58	10	55	18	42.8	32
64 Spin Recovery (FLF)	58	8	53	20	36.5	28
65 Spin Recovery (FHS)	33.5	12	46	32	34	14
66 Spin Recovery (FHF)	48	12	45	32	34.3	12
67 Spin Recovery (AL)	50	10	57.5	15	42.5	37

[1] High ranks represent high criticality.
[2] High ranks represent low decision-making effectiveness.

FIGURE 6-4. (CONTINUED)
MEAN RANKS AND AGREEMENT SCORES FOR EMERGENCY SITUATION ATTRIBUTES

MEAN RANK	SAFETY CRITICALITY	TIME CRITICALITY	DECISION-MAKING EFFECTIVENESS
0 - 9.9	6	6	0
10 - 19.9	12	6	0
20 - 29.9	10	5	13
30 - 39.9	7	15	27
40 - 49.9	16	9	15
50 - 59.9	7	12	0
60 - 67	2	2	0

FIGURE 6-5.
FREQUENCY DISTRIBUTION OF MEAN RANKS FOR SAFETY CRITICALITY, TIME CRITICALITY AND DECISION-MAKING EFFECTIVENESS

AGREEMENT SCORES	SAFETY CRITICALITY	TIME CRITICALITY	DECISION-MAKING EFFECTIVENESS
0 - 9.9	31	33	3
10 - 19.9	19	3	8
20 - 29.9	8	9	8
30 - 39.9	0	5	13
40 - 49.9	2	0	15
50 - 59.9	0	0	8
60 - 67	0	0	8

FIGURE 6-6.
FREQUENCY DISTRIBUTION OF AGREEMENT SCORES FOR SAFETY CRITICALITY, TIME CRITICALITY AND DECISION-MAKING EFFECTIVENESS

good agreement among pilots for the safety and time criticality rankings, but not for the rankings for decision-making effectiveness. For the latter attribute, the majority of situation rankings showed lower agreement than for most time criticality and most safety criticality scores. These data suggest that pilots are unable to produce reliable rankings of their effectiveness and training in this area. It may be that the effectiveness of their training varies widely or that they are simply not used to making such judgments. The relatively low agreement scores for these ranks, coupled with the lack of discrimination (bunching) found, indicate that the rankings for decision-making effectiveness obtained in the present study are of little value at this time and they will not be considered further. However, the very contrast between these rankings and those for safety and time criticality has two interesting implications. On the one hand, it suggests that the method used does produce reliable data for those concepts which are well understood by the pilots, namely the concepts of time and safety criticality. On the other hand, the finding that rankings of decision-making effectiveness were found to be unreliable implies that decision making and its importance in dealing with emergencies is not sufficiently emphasized during training.

The frequency distributions were used to select cut-off points so as to divide the rankings into three parts reflecting high, medium, and low safety and time criticality scores. Ranks between 0 and 19.9 were labeled low, 20 to 39.9 were medium, and high scores had rankings between 40 and 67. Figure 6-7 shows the emergency situations categorized in a 3x3 matrix as either high, medium, or low on each dimension. The numbering for conditions is the same as that shown in Figure 6-4. Only ranks for which the agreement scores were 30 or below were considered for this figure.

		TIME CRITICALITY			
		HIGH (0 - 19.9)	MEDIUM (20 - 39.9)	LOW (40 - 67)	Σ
SAFETY CRITICALITY	HIGH (0 - 19.9)	3, 4, 5, 6, 8, 9, 10, 14, 28, 57, 58, 59, 62, 63, 64, 67	7, 15, 16, 24, 25		21
	MEDIUM (20 - 39.9)	2, 11, 22, 23	21, 26, 27, 52, 53, 54	17, 18, 29	13
	LOW (40 - 67)	12, 36, 37, 38, 39	13, 19, 35, 60, 61	20, 30, 31, 32, 33	15
	Σ	25	16	8	49

FIGURE 6-7.
CLUSTERS OF EMERGENCY SITUATIONS CATEGORIZED BY RANK ORDER ON SAFETY AND TIME CRITICALITY (SITUATION NUMBERS CORRESPOND TO THOSE IN FIGURE 6-4)

The situations are fairly well distributed over all cells in Figure 6-7. The relatively large number of situations in the high safety/high time criticality cell is due to the initial selection of emergency situations which stressed high safety criticality. No situation having high safety criticality also has low time criticality; in other words, for all highly safety-critical situations, time criticality is either high or medium. On the other hand, there are a few situations having high time criticality, but for which the safety criticality is low. All five situations in this cell occur at high altitude, at either fast or slow speed. Situation #12 is stall/stagnation, inflight high and slow. Situations #36 and #37 are low fuel pressure, inflight high, fast and slow, and situations #38 and #39 are low oxygen with the same flight phases as #36 and #37.

The distribution of the malfunctions in the matrix suggests that the criticality of some malfunctions is much more dependent on flight phase than others. For example, total engine failure is almost always high on both safety and time criticality, although the rankings suggest that there is somewhat more time to react when flying high and fast than during other flight phases. On the other hand, the rankings for engine stall or stagnation suggest that the criticality of this malfunction depends much more on flight phase than that of total engine failure. Both time and safety criticality are high for an engine stall or stagnation during final takeoff, inflight low and slow, and approach and landing; time criticality is still high, but safety criticality is low for the same emergency inflight high and slow.

The breakdown of emergency situations into related clusters as shown in Figure 6-7 may be of some value in designing training strategies for emergency situations. The nature of situational variables to be represented, the permissible response time, and the decision rule to be

employed, all need to be specified when a strategy for developing the skill to deal with a particular emergency is chosen. The degree of risk and the time available for decision making would undoubtedly influence the selection of these factors and the evaluation of the skills being developed. To the extent that groupings of situations, as are made in Figure 6-7, validly reflect common characteristics of a set of emergencies, it should be possible to adopt a common training strategy which takes these commonalities into account.

6.6 Decision Types

The 67 emergency situations ranked in the preceding sections were also ranked in terms of two major decision activities--problem structuring and alternative selection. The same general technique as used in preceding sections of this chapter was used here. Six pilots served as experts. They were asked to rank-order the 67 emergency situations with respect to the relative difficulty of either problem structuring or alternative selection. Because the task is fairly difficult and time consuming, each pilot rank-ordered the situations according to only one of the two decision activities. The instructions to the pilots were as follows:

> Several components are included in the process of making a decision. We are interested in how difficult it is to make decisions when dealing with emergency situations. I will give you a set of cards, each having a particular malfunction paired with a flight phase. Please rank them in terms of how difficult they are with respect to problem structuring (alternative selection).

The three pilots who ranked the cards according to the difficulty of problem structuring were told that problem structuring involves both a recognition of the problem and acquisition of more information concerning it. They were shown Figure 6-8 which contains a list of questions pertaining to those two components and which was to be used as a guide to assessing difficulty. The three pilots who were asked to rank situations according to difficulty of alternative selection were told that alternative selection involves defining the available options and selecting the best course of action. They were shown Figure 6-9 which contains relevant questions to be used as a guide. All pilots were asked to visualize each emergency situation when they considered the questions relevant to the difficulty of the decision type being ranked.

Mean ranks and agreement scores were obtained in the same manner as before. The results for problem structuring and alternative selection are shown in Figure 6-10. The situation numbers are the same as those used in Figure 6-4. In certain cases pilots did not rank some of the 67 conditions. Low scores on problem structuring and alternative selection represent easy problems, while high scores represent difficult problems.

The distributions of the mean ranks are shown in Figure 6-11 and of the agreement scores in Figure 6-12. As before, the mean ranks are fairly well distributed over the range, and the agreement scores are bunched up at the low end of the distribution. The high correspondence in rankings by pilots is shown by the low agreement scores, which suggests that the task was meaningful and valid. The cut-off criteria for easy tasks were 0 to 19.9, for tasks with medium difficulty, 20 to 29.9, and for difficult tasks, they were 30 to 49.9. These criteria were the same for the problem structuring and the alternative selection tasks.

RECOGNIZING THE PROBLEM

a. How easy/difficult is it to recognize exactly what the problem is?

b. What are the variables, or factors, which affect the situation you are in?

c. How easy/difficult is it to identify those factors?

d. Are the various possible outcomes of this situation easy/difficult to identify?

e. Is there a big difference between the present (emergency) condition and the condition which would prevail if there were no emergency? (The larger the difference, the more complex or difficult.)

f. Is it easy/difficult to know exactly which factors should be changed so as to eliminate the emergency?

OBTAINING MORE INFORMATION ABOUT THE PROBLEM

a. How easy/difficult is it to obtain more information about this emergency condition?

b. How many sources of information can you rely on?

c. How reliable are those sources?

d. Are those sources available to you?

e. Is it easy/difficult to decide which are the most promising sources (sources with the most useful information)?

f. Is it easy/difficult to know at what point you have enough information to solve the problem?

g. What is the cost of these sources (e.g., you may have a very reliable source available with very good information, but it might take too long to obtain this information: the source is good, but the cost is high).

FIGURE 6-8.
GUIDELINES FOR JUDGING DIFFICULTY OF PROBLEM STRUCTURING

DECIDING WHAT OPTIONS ARE AVAILABLE IN SOLVING THE PROBLEM

a. Is it easy/difficult to select one best course of action?

b. How many different options do you think you have in solving the problem? (The more options, the more difficult)

c. Are all these options practical? (If most of them are not pratical, the level of difficulty goes down)

d. Are some of these options contingent upon specific outcomes or environmental events? If so, are the contingencies realistic? (The more contingencies, the more difficult)

SELECTING THE BEST OPTION

a. How easy/difficult is it to evaluate the various options you have?

b. How easy/difficult is it to select the best one?

c. What do you base your selection on? Is it easy/difficult to decide?

d. Is it easy/difficult to assess the risks involved in taking each of the possible actions?

FIGURE 6-9.
GUIDELINES FOR JUDGING DIFFICULTY OF ALTERNATIVE SELECTION

SITUATION NUMBER	PROBLEM STRUCTURING MEAN RANK	PROBLEM STRUCTURING AGREEMENT SCORE	ALTERNATIVE SELECTION MEAN RANK	ALTERNATIVE SELECTION AGREEMENT SCORE
1	6	6.7	11.7	4
2	7.6	18.7	13.3	13.3
3	6.7	3.3	8	8
4	14.3	11.3	8.3	6.7
5	18.7	9.3	28.3	12
6	18	7.3	28	10.7
7	20	8.7	27.7	9.3
8	11.7	10	7.3	7.3
9	29	11.3	26.3	20.3
10	29.7	10	39.3	14
11	28.3	6.7	37	14.7
12	25.7	10.7	37	16.7
13	26	6.7	34.7	16
14	29.3	11.3	35	17.3
15	43	6	20.7	6
16	43.3	6	19.3	6.7
17	44.7	9.3	22.3	8.7
18	43.3	12.7	20.7	8.7
19	24.3	34.7	27.3	28
20	23	21.3	31.7	27.3
21	28.7	28.3	29.7	18
22	31	26.7	32.7	18.7
23	21.3	25.3	44.7	2
24	34	20.7	45.7	2.7
25	30.7	20	41	8.7
26	30.3	24	43.3	2.7
27	33	21.3	42.7	3.3
28	33.3	25.3	44	5.3
29	40	2	13.3	5.3
30	13.3	16	36.3	21.3

FIGURE 6-10.
MEAN RANK AND AGREEMENT SCORES FOR DECISION COMPONENTS OF EMERGENCY SITUATIONS (SITUATION NUMBERS CORRESPOND TO THOSE IN FIGURE 6-4)

SITUATION NUMBER	PROBLEM STRUCTURING MEAN RANK	PROBLEM STRUCTURING AGREEMENT SCORE	ALTERNATIVE SELECTION MEAN RANK	ALTERNATIVE SELECTION AGREEMENT SCORE
31	14.3	11	35	20.7
32	13.3	16	34.3	22.7
33	14.3	16	33	22
34	44	6	37	16
35	43	6	36.3	15.3
36	32.7	10	23	10.7
37	33	10	23.7	10.7
38	47	12.7	14	3.3
39	46.7	12.7	14.7	3.3
--				
50	14.5	15	38.5	1
51	14.5	13	38.5	1
52	8	16.7	22	2
53	8.7	9.7	19.3	6.7
54	12	14	21.7	3.3
--				
57	19.3	5.3	8	6
58	24.7	16	9.3	5.3
59	30.5	20	20	23.3
60	27.3	14	34.7	10
61	37	16	35	8
62	28	14	16	11.3
63	18	14	6.7	7.3
64	26		6.7	8
65	27	19.3	38.3	10.7
66	34.5	15	39	20
67	24		10	6.7

FIGURE 6-10, (CONTINUED)
MEAN RANK AND AGREEMENT SCORES FOR DECISION COMPONENTS OF EMERGENCY SITUATIONS (SITUATION NUMBERS CORRESPOND TO THOSE IN FIGURE 6-4)

MEAN RANK	PROBLEM STRUCTURING	ALTERNATIVE SELECTION
0 - 9.9	5	7
10 - 19.9	13	9
20 - 29.9	17	14
30 - 39.9	11	19
40 - 49.9	9	6

FIGURE 6-11.
FREQUENCY DISTRIBUTION OF MEAN RANKS FOR PROBLEM STRUCTURING AND ALTERNATIVE SELECTION

AGREEMENT SCORES	PROBLEM STRUCTURING	ALTERNATIVE SELECTION
0 - 9.9	16	29
10 - 19.9	26	17
20 - 29.9	10	9
30 - 39.9	1	0

FIGURE 6-12.
FREQUENCY DISTRIBUTION OF AGREEMENT SCORES
FOR PROBLEM STRUCTURING AND ALTERNATIVE SELECTION

As before, the emergency situations were classified in a 3x3 matrix as either high, medium, or low on each dimension, as shown in Figure 6-13. The situation numbers are again the same as those used in Figure 6-4. Only those situations having an agreement score of 30 or better were entered into the matrix. Because the agreement on this task was slightly better than on the task requiring rankings of safety and time criticality, only one score (on situation #19: stuck throttle on final takeoff) was eliminated from this matrix due to low agreement.

Figure 6-13 shows how the emergency situations are clustered according to mean difficulty rankings for the two decision-making activities each situation involves. As with the time and safety criticality rankings, the difficulty of the decisions involved for a given emergency condition was sometimes independent of flight phase, and sometimes very much dependent on the flight phase. For example, both decision activities were considered difficult in the case of an engine fire in all flight phases except during initial and final takeoff, which were ranked to be of medium difficulty on either problem structuring or alternative selection. In other words, flight phase does not appear to be an important consideration in determining the difficulty of dealing with an engine fire. This is not the case for the difficulty of stall/departure decisions (situations #63 to #67) which are distributed across 5 of the 9 cells, depending on the flight phase.

The groupings of these situations according to the difficulty of the decision activities involved, as shown in Figure 6-13, suggests conclusions comparable to those made when these situations were clustered according to safety and time criticality (Figure 6-7), namely that these clusters may be of some value in designing training strategies. It should be possible to prepare common approaches to training for clusters

		ALTERNATIVE SELECTION			
		DIFFICULT (30 - 49.9)	MEDIUM (20 - 29.9)	EASY (0 - 19.9)	∑
PROBLEM STRUCTURING	DIFFICULT (30 - 49.9)	22, 24, 25, 26, 27, 28, 34, 35, 61, 66	15, 17, 18, 36, 37, 59	16, 29, 38, 39	20
	MEDIUM (20 - 29.9)	10, 11, 12, 13, 14, 20, 23, 60, 65	7, 9, 21	58, 62, 64, 67	16
	EASY (0 - 19.9)	30, 31, 32, 33, 50, 51, 57, 63	5, 6, 52, 54	1, 2, 3, 4, 8, 53	18
	∑	27	13	14	54

FIGURE 6-13.
CLUSTERS OF EMERGENCY SITUATIONS CATEGORIZED BY DIFFICULTY LEVEL ON PROBLEM STRUCTURING AND ALTERNATIVE SELECTION (SITUATION NUMBERS CORRESPOND TO THOSE IN FIGURE 6-4)

of specific emergencies which involve similar types of decision making activities and similar levels of difficulty.

Figure 6-14 summarizes the data obtained from all of the expert interviews with the exception of data for decision-making effectiveness which was found to be unreliable. Based on the difference between the designations on problem structuring and alternative selection, a decision type was assigned to each situation. The decision types are 1 (mostly problem structuring), 2 (mostly alternative selection), 3 (problem structuring and alternative selection - complete decision), and B (mostly Boldface procedures). A decision type B was assigned when both the problem structuring and alternative selection were considered easy by the pilots. If only one of these components was considered easy, the decision type assigned was a 1 or a 2, depending on which component was easy. If both components were rated as medium or high in difficulty, the decision type was 3; that is, the situation involved both components fairly extensively.

As can be seen from Figure 6-14, many situations require a complete decision. In general, situations which were rated easy with respect to the two decision-making activities were also highly critical with respect to safety and time, suggesting that Boldface-like procedures are or should be available to deal with such dangerous situations. At the same time, however, there are eight situations which are rated high on both safety and time criticality, and which also have ranks of medium or high difficulty on the decision-making activities. It appears that training which goes beyond a Boldface-like approach and involves substantial decision skills would be particularly desirable for such situations, if these data are at all reliable.

SITUATION NUMBER	SAFETY CRITICALITY			TIME CRITICALITY			PROBLEM STRUCTURING			ALTERNATIVE SELECTION			DECISION TYPE			
	HIGH	MED	LOW	HIGH	MED	LOW	DIFF	MED	EASY	DIFF	MED	EASY	1	2	3	B
1		X							X			X				X
2		X		X					X			X				X
3	X			X					X			X				X
4	X			X					X			X				X
5	X			X					X		X			X		
6	X			X					X		X			X		
7	X				X			X			X				X	
8	X			X					X			X				X
9	X			X				X			X				X	
10	X			X				X		X					X	
11		X		X				X		X					X	
12			X	X				X		X					X	
13			X		X			X		X					X	
14	X			X				X		X					X	
15	X				X		X				X				X	
16	X				X		X					X	X			
17		X				X	X				X				X	
18		X				X	X				X				X	
19			X		X						X					
20			X			X		X		X					X	
21		X			X			X			X				X	
22		X		X			X			X					X	
23		X		X				X		X					X	
24	X				X		X			X					X	

FIGURE 6-14.
SUMMARY OF MEAN RANKS ON SITUATIONS WITH AGREEMENT SCORES OF 0-30
(SITUATION NUMBERS CORRESPOND TO THOSE IN FIGURE 6-4)

SITUATION NUMBER	SAFETY CRITICALITY			TIME CRITICALITY			PROBLEM STRUCTURING			ALTERNATIVE SELECTION			DECISION TYPE			
	HIGH	MED	LOW	HIGH	MED	LOW	DIFF	MED	EASY	DIFF	MED	EASY	1	2	3	B
25	X				X		X			X					X	
26		X			X		X			X					X	
27		X			X		X			X					X	
28	X			X			X			X					X	
29		X				X	X					X	X			
30			X			X			X	X				X		
31			X			X			X	X				X		
32			X			X			X	X				X		
33			X			X			X	X				X		
34			X				X			X					X	
35			X		X		X			X					X	
36			X			X	X				X				X	
37			X			X	X				X				X	
38			X			X	X					X	X			
39			X			X	X					X	X			
--																
48			X													
49			X													
50									X	X				X		
51					X				X	X				X		
52		X			X				X		X			X		
53		X			X				X			X				X
54		X			X				X		X			X		
55						X										
56						X										

FIGURE 6-14 (CONTINUED).
SUMMARY OF MEAN RANKS ON SITUATIONS WITH AGREEMENT SCORES OF 0-30
(SITUATION NUMBERS CORRESPOND TO THOSE IN FIGURE 6-4)

SITUATION NUMBER	SAFETY CRITICALITY			TIME CRITICALITY			PROBLEM STRUCTURING			ALTERNATIVE SELECTION			DECISION TYPE			
	HIGH	MED	LOW	HIGH	MED	LOW	DIFF	MED	EASY	DIFF	MED	EASY	1	2	3	B
57	X			X					X			X				X
58	X			X				X				X	X			
59	X			X			X				X				X	
60			X		X			X		X					X	
61			X		X		X			X					X	
62	X			X				X				X	X			
63	X			X					X			X				X
64	X			X				X				X	X			
65		X						X		X					X	
66	X						X			X					X	
67	X			X				X				X	X			

FIGURE 6-14 (CONTINUED).
SUMMARY OF MEAN RANKS ON SITUATIONS WITH AGREEMENT SCORES OF 0-30
(SITUATION NUMBERS CORRESPOND TO THOSE IN FIGURE 6-4)

Some preliminary guidelines for training are suggested by Figure 6-13 when the decision type assignments for emergency situations are reviewed. The situations which involve difficult or moderate levels of problem structuring and/or alternative selection would appear to be candidates for training programs which emphasize development of decision skills. Situations low on difficulty for these activities would be candidates for Boldface training procedures, assuming high time and safety criticality were involved also.

Unfortunately, data obtained to assess the current decision-making effectiveness of pilots were unreliable and can not be used to indicate whether current training is or is not effective with respect to the development of decision skills. The high variability of these data, together with informal conversations with the pilots who provided them, support the impression that current training programs do not explicitly address decision skills in any formal manner, but concentrate instead on developing situation specific procedural skills.

It was noted earlier that in several cases the experts used in this study were unable to agree on the ratings for particular attributes of a given emergency condition. There may be several reasons for the lack of agreement obtained in some of the judgments. First, the malfunctions may be objectively different for different aircraft. Second, pilots may rate situations differently because they have had different previous experiences. For instance, if a situation has never actually been experienced by a pilot, his only basis for rating it is second-hand knowledge obtained perhaps from manuals or conversations with other pilots. On the other hand, having actually experienced a particular malfunction adds a different perspective to one's evaluation of it. Third, the subjective interpretation of the attribute being used for the rating may vary. Fourth, the experts' perceptions of the probability of an outcome

as well as of the severity of the potential outcome of a situation may vary over malfunctions. That is, one malfunction may be viewed as possibly critical, whereas another may be seen as certain to be critical. Differences in perception may also reflect each expert's view of the likelihood that appropriate corrective action can be initiated.

In the present data, all these reasons are treated as possible sources of error. To eliminate them, it would be necessary to specify the conditions of an emergency in great detail and to obtain ratings from a large number of pilots. This was not a necessary condition at this time, since the purpose of this study was only to derive a relatively good representative sample of emergency situations. Nevertheless, the lack of agreement found in some ratings may serve to indicate an underlying difference between situations for which there is a consensus and those for which there is not. It may be that the number of situational factors affecting the complexity and the outcome of an emergency is reflected inversely by the degree of agreement obtained on the attribute values. High consensus in judging attributes suggests that the outcome of an emergency is quite clearly defined by the emergency itself, whereas low consensus may mean that the attributes of an emergency are much more situationally dependent. Conversations with the experts about the ratings assigned served to support this interpretation, namely, that the variability of ratings for certain emergency situations reflected the number of situational contingencies which had to be taken into account in trying to come up with a single ranking for the emergency.

If attribute judgments had been obtained with a much larger sample of experts, it is possible that the variability of estimates, within reasonable limits, would serve as a useful index of the need to include contextual variations in training materials for individual malfunctions. For example, if high consensus is obtained, the emergency condition may

not need to be presented in many different guises; on the other hand, low consensus would suggest that the outcome of an emergency is highly dependent on situational events, so that the low-consensus malfunction should be included for study in many different situations. It would be interesting to test this hypothesis in a more extensive study. Another point to bear in mind is that the nature of a malfunction or emergency condition will vary with the aircraft involved, but that present data do not allow for this refinement, which should also be addressed in more detail in an expanded study.

It is important to bear in mind that while this study has only presented single estimates, rather than distributions of the values of the attributes assessed, distributional information could be obtained with a more extensive effort than the present study using the same general method. Distributional or base-rate information is a source of information that is frequently overlooked in making predictions (Kahneman and Tversky, 1977) and one that characterizes outcomes in cases of the same general class, in contrast to singular information, which describes specific features of the problem distinguishing it from others in the same general class. Such data could be important as a basis for guiding decision training programs, because they address a significant bias in decision making. Kahneman and Tversky (1977) found that, in general, people give insufficient weight to distributional data and rely primarily on singular information in predicting outcomes of decision situations. Deviations from optimal decision making may be attributed to this bias, a source of error that could be corrected without too much difficulty if distributional data were available and its value emphasized.

The study reported here dealt only with one of several types of emergencies, namely emergencies induced by malfunctions. The major reason for this is that malfunction-related emergencies can be fairly easily

defined and that they represent a large set of events which are important from a safety and training standpoint. Decision-related information concerning malfunctions can be more easily obtained during interviews than similar information for emergencies which are more abstract (e.g., communications problems, operator error). The intention was not to enumerate all possible malfunctions that occur, but rather to derive an overview of the types of malfunctions and their concomitant problems that need to be considered in developing a taxonomy to be used as a basis for generating training guidelines.

7. EMERGENCY SITUATION MODELS AND TRAINING IMPLICATIONS

7.1 Introduction

The preceding two chapters described efforts carried out to identify aspects of aircraft emergencies which can be used by training designers and developers as a backdrop for the preparation of aircrew emergency decision training programs. The data reported were derived empirically from reviews of aircraft accident reports and from expert interviews with military pilots. The present chapter takes a much more theoretical orientation in that it proposes three related models for representing the aircraft emergency situation. A taxonomic scheme is developed for classifying the attributes of an emergency in light of factors in the representational models. Finally, some initial guidelines for training are proposed which draw on the implications from the models and the proposed taxonomy.

7.2 Representative Models of the Emergency Situation

In order to lay the foundation to develop procedures for training and scenario generation, the situations to be trained for need to be organized in such a way that their components have some relevance to the desired performance and that the behavior can be differentially related to various aspects of these components. The following section describes three models which differentially relate emergency situation to behavioral variables. These three models are (1) an objective event model, corresponding to external events and representing an objective description of an emergency situation; (2) a decision model describing the conscious processes needed to deal with an emergency, specifically the components of the decision-making situation; and (3) a cognitive

model, describing a theoretical view of the learning and memory processes that take place during training and in actual emergencies.

7.2.1 Event Sequence. Emergency situations can be the result of any number of factors, including those that are directly related to the pilot, such as physiological disturbances or psychological stress, communication break-downs, and so forth. Ideally, all types of emergencies should be included in a training program and should be described by an event model. For the time being, however, only malfunction-induced emergencies are considered. Similarly, causes or influences antecedent to a malfunction are excluded from the present conceptualization.

The event sequence represents an objective view of the components which must be considered in developing training guidelines for emergency procedures. These are shown in Figure 7-1. By definition, the event sequence begins with a malfunction that is manifested by a pattern of cues. From the pilot's point of view, it is the information obtained from the cues that starts the sequence of dealing with an emergency. This information is defined by the values of the cue attributes. When cues are perceived and interpreted, they lead to certain actions that are described by the decision model and the cognitive model to be discussed below. These actions may lead to the identification of the malfunction or to intermediate outcomes that produce new cues until the problem is solved.

The cues must not only be interpreted for an immediate decision with respect to their cause and a possible solution to the emergency, but some anticipatory decisions must be made at this time, predicting the probable changes in the cues as a function of time and the consequences thereof. Both decision types are described below, and comprise the decision model.

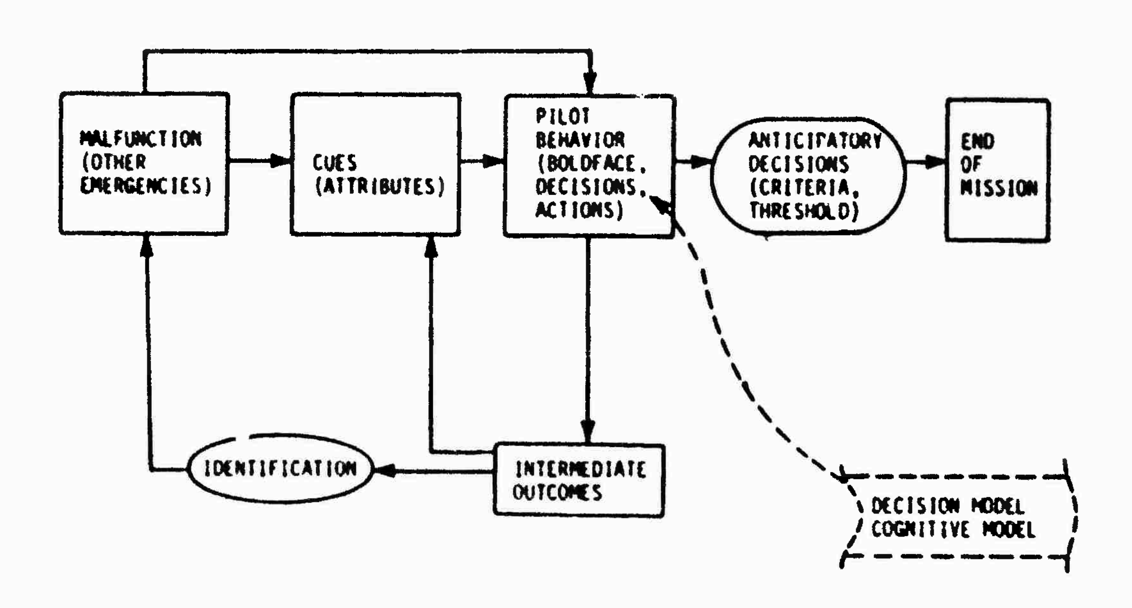


FIGURE 7-1.
EVENT SEQUENCE FOR EMERGENCY SITUATIONS

7.2.2 Decision Processes. For present purposes, two basic types of decisions will be distinguished. The first is the ongoing decision which requires immediate or continuing attention. The second is the anticipatory decision which may be executed at a later point in time. The two types of decisions are represented separately because they have some distinguishing characteristics, and because there seems to be an inherent difference between decisions concerning the problems brought about by a malfunction and decisions such as those involving ejections and abortive takeoffs. The first type--the ongoing decision--can be conceptualized as a classic decision, which includes problem structuring aspects as well as alternative selection and evaluation of outcomes. The second type involves anticipations concerning decisions that may have to be made at some future time, but because the time frame for executing this type of decision is so critical, the conditions and criteria for executing it must be predetermined. The relevant components of these two types of decisions are shown in Figures 7-2 and 7-3, respectively.

Theoretically, the ongoing decision contains all the components identified in a complete decision (Figures 7-4 and 7-5), although in practice, some components may be irrelevant in specific cases. Two additional processes, hypothesis generation and confidence rating, are shown in Figure 7-2, because these may affect the manipulation and processing of the subsequent components. That is, it is assumed that problem recognition and structuring leads to the generation of hypotheses concerning the accuracy of this activity, and that the amount of confidence the decision maker has in how much of the problem has in fact been identified, is likely to affect the type and number of alternatives that will be examined, which, in turn, could influence subsequent phases of the

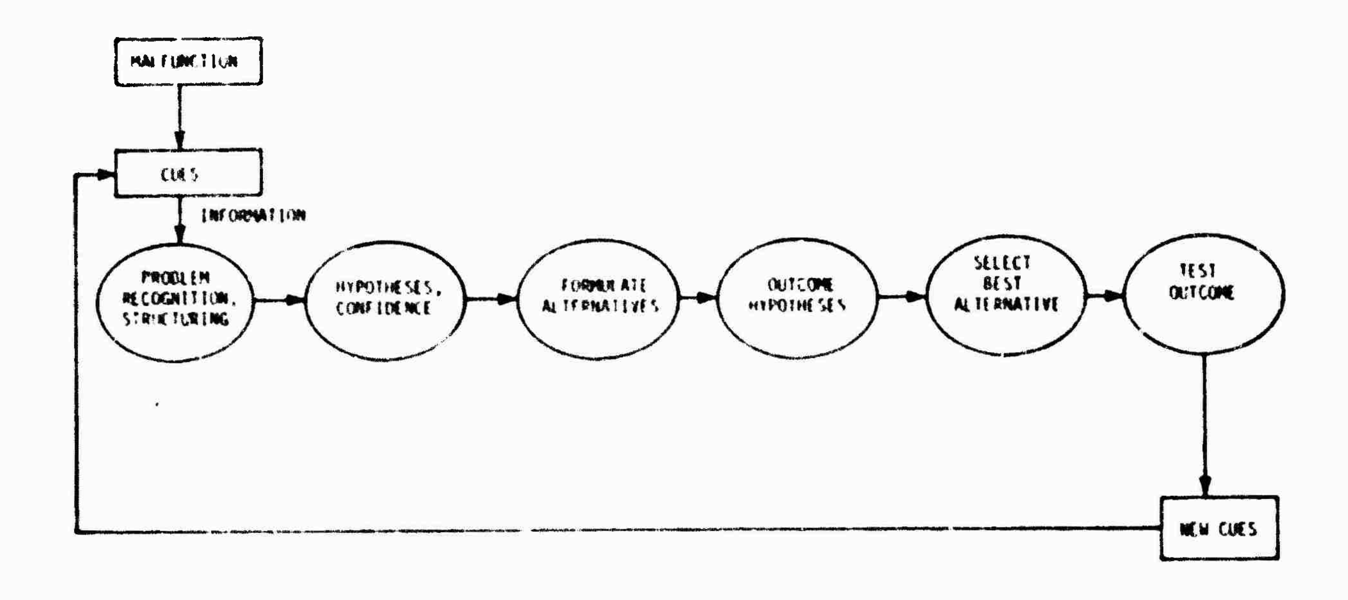


FIGURE 7-2.
COMPONENTS OF ONGOING DECISION

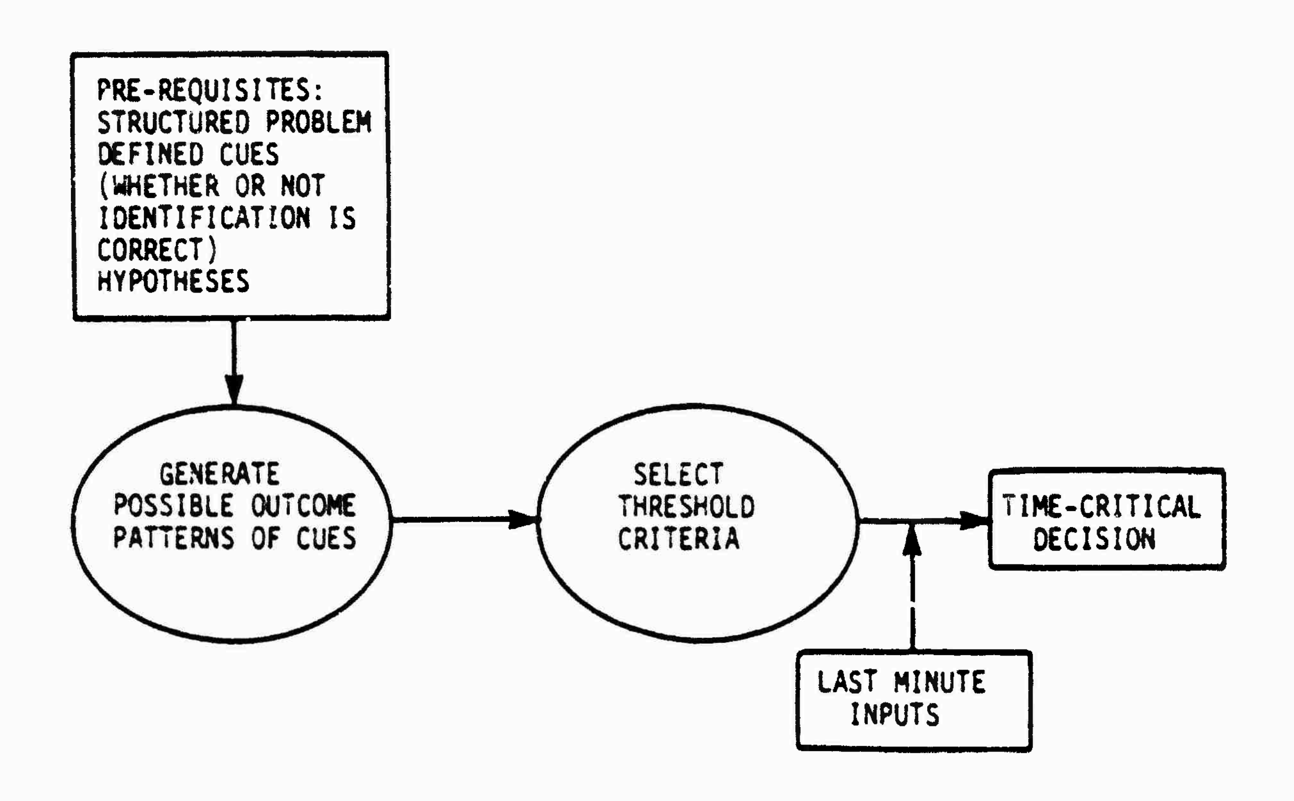


FIGURE 7-3.
COMPONENTS OF ANTICIPATORY DECISION

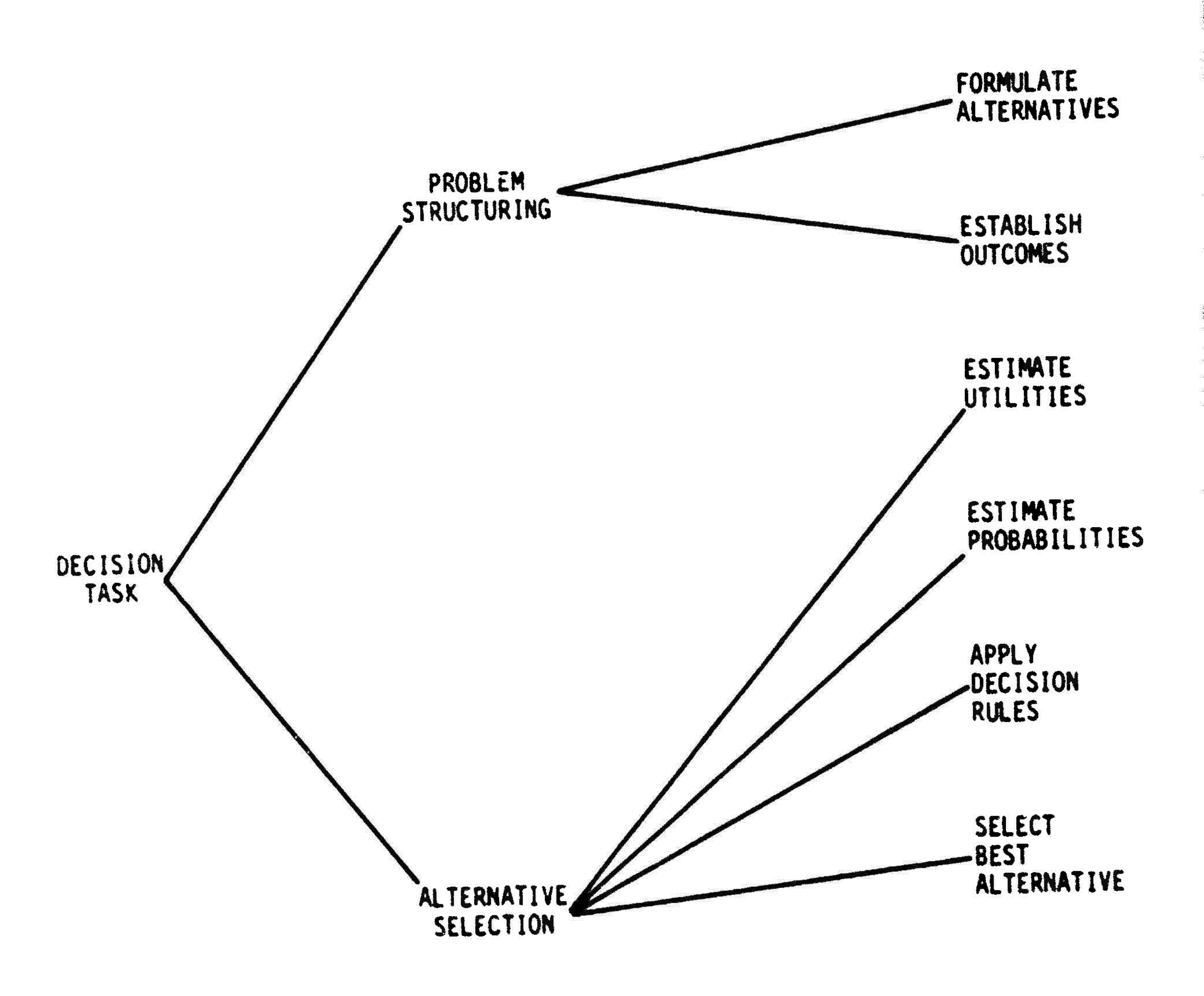


FIGURE 7-4.
DECISION TASK COMPONENTS

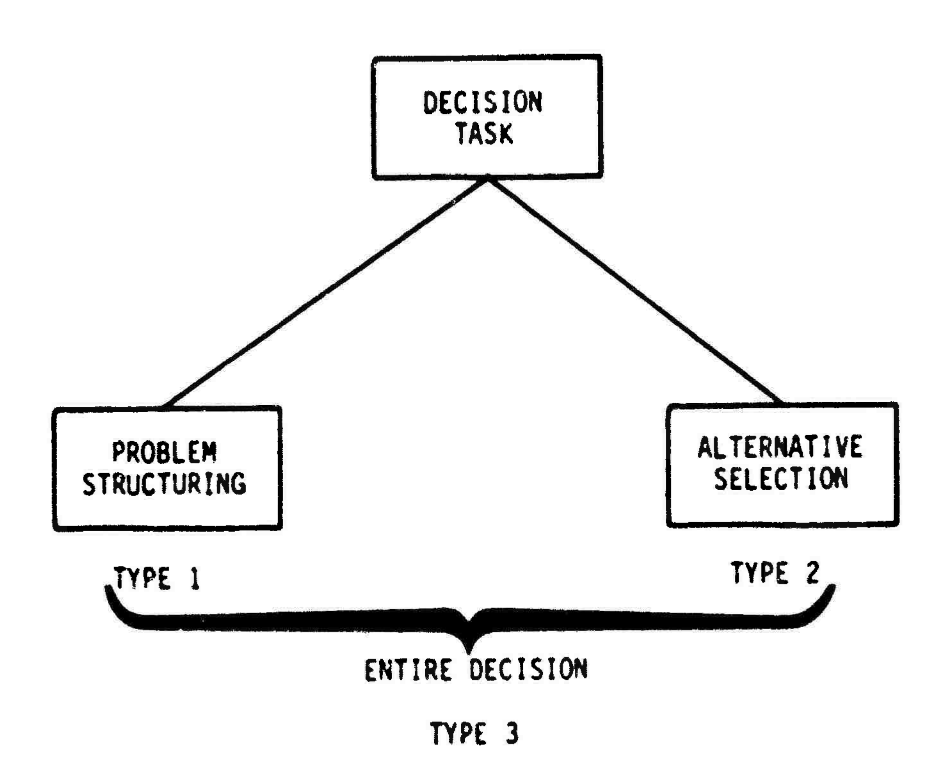


FIGURE 7-5.
DECISION TASK TYPES

decision process. No research is available concerning this assumption and it is only presented as a possible consideration for future experimentation.

Figure 7-2 shows the stages of information processing of the ongoing decision. When a pattern of cues is perceived as deviating from the "normal" expected pattern of information, the deviation is a signal that something may be wrong. Problem recognition occurs, which is followed by problem structuring. The success of problem structuring is a function of the attribute values of the cues (reliability, salience, etc.), and these values in turn influence the degree of confidence a pilot has in his hypotheses concerning the malfunction. Very little is known concerning possible differences in how alternatives are formulated and selected, given different degrees of confidence in the problem structuring phase. Confidence is influenced by the degree of consistency among cues, and it determines the amount of additional information that is sought. The more inconsistency there is, the more information is needed to resolve it. One bias that has been described (Elstein, Shulman, and Sprafka, 1978) is that decision-makers tend to seek evidence confirming their initial hypothesis and neglect trying to disconfirm the hypothesis, even if their confidence in the initial hypothesis is low.

When the alternatives have been formulated, hypotheses concerning the outcomes under each alternative are generated and a decision rule applied for selecting the best alternative. The outcomes following each action are tested against the hypotheses and the resultant information is used to start the decision loop anew until the problem is solved or the mission ended.

The anticipatory decision (Figure 7-3) begins when the cues have been identified and defined, and the problem has been structured. Confidence

in the accuracy of this phase is not relevant at this point. What is relevant is that, given a malfunction and/or cues, there are certain probabilities associated with the way these cues can change over time and with the possibility of having to abort a mission, eject, or perform a forced landing. At the moment decisions such as these have to be executed, it is too late to follow the rules of decision analysis. Therefore, the anticipatory decision is one in which the factors are anticipated and threshold criteria for executing the decision are preselected. Anticipatory decisions involve the generation of hypotheses concerning how the available cues may change over time and the specification of threshold values beyond which the changes require immediate action (e.g., ejection). Criteria for decision execution may also take new cues or changes in situational events into account.

The differences in the two classes of decisions are shown in Figure 7-6. For ongoing decisions dealing with malfunctions, the actions are discrete and determined by the cues as perceived at the moment. The outcomes are probabilistic in the sense that they may depend on factors that are not predictable, or they may depend on the accuracy of the problem recognition and structuring phase; the outcomes are also probabilistic because the estimated utilities determine the selection of the alternative actions. For anticipatory decisions, on the other hand, the actions are probabilistic and the outcomes are determined. The actions are probabilistic because they depend on a critical threshold that may or may not be reached, and on the anticipated changes in the cues. Once the threshold is reached, the outcomes are well-defined since they are a function of the anticipatory decision. The outcome utilities do not affect the event alternatives since these are determined by extraneous factors that are not under the control of the pilot. The utilities are known, and the outcome is not a function of the pilot's decisions

	ACTIONS	OUTCOMES	UTILITIES
ONGOING DECISIONS DEALING WITH MALFUNCTIONS	DISCRETE SET DETERMINED	PROBABILISTIC	ESTIMATED
ANTICIPATORY DECISIONS	THRESHOLD-DEPENDENT PROBABILISTIC	WELL-DEFINED	KNOWN

FIGURE 7-6.
DISTINCTIONS BETWEEN DECISION CLASSES

(although it is related to the type of malfunction that occurred and to how the pilot dealt with it).

The critical problem for anticipatory decisions is to recognize the changes in the relevant cues and the degree of changes that can be tolerated. Expert data obtained during interviews suggest that there is no objective way to define these changes, that they are a function of experience and "feel" for the aircraft. These same data also suggest that, while the threshold criteria may be successfully predetermined, the problem lies in the actual execution of the decision, especially in the case of a decision to eject. According to one expert pilot, there may be an interesting difference in this respect between experienced and inexperienced pilots. Although inexperienced pilots may know how to set the criteria, they may not follow through with their decisions or, for reasons such as lack of confidence and fear of repercussions, they may change their mind at the last minute. Experienced pilots tend to make the opposite error: once they make an anticipatory decision, they tend to stay with it, even when new information is obtained that would suggest a change. From a training point of view, it would seem desirable to investigate the possible reasons for this experience-related difference, and find out if it is possible to influence both tendencies--the one that delays the execution of the decision and the one that ignores new information.

The decision processes represented here can be trained directly, because these are processes of which the pilot is aware. Knowledge structures can be developed that include the relevant elements of decision making and the decision rules appropriate in specified circumstances.

7.2.3 Cognitive Processes. The cognitive processes model is shown in Figure 7-7. It is loosely patterned after the classic TOTE (test-

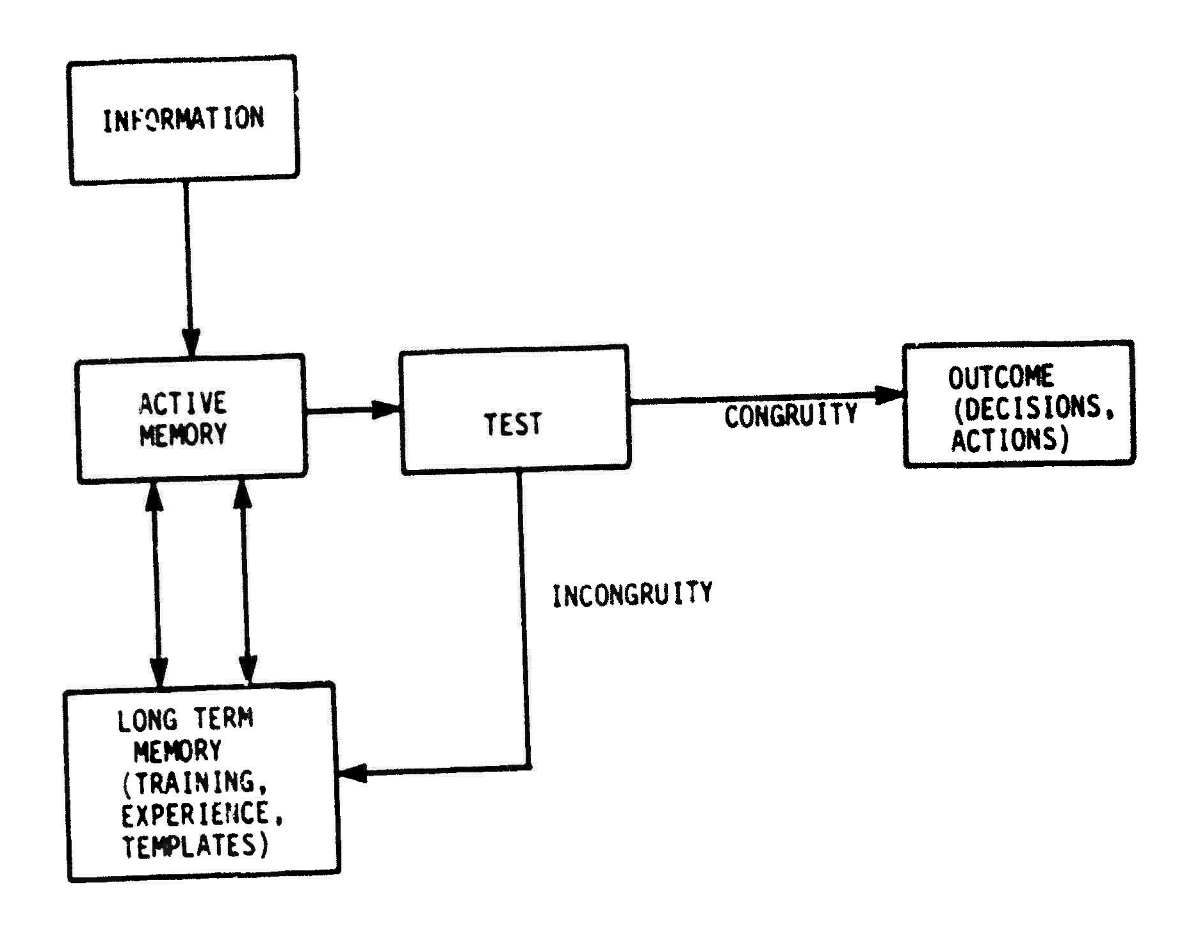


FIGURE 7-7.
COGNITIVE PROCESS MODEL

operate-test-exit) unit of Miller, Galanter, and Pribram (1960) that assumes a feedback loop, whereby inputs from the environment are tested for congruity against some established criteria. If the test is positive, the input information is congruous with the information available in active memory, and an action can be taken. If the test leads to incongruity, additional information from long-term memory (LTM) must be activated until the results of the test are congruous.

In the present model, some additional assumptions are made concerning the organization of LTM and the processes whereby items are entered into active memory. LTM is assumed to consist of numerous systems, each representing a meaningful cluster of related information. These "representational systems" are analogous to the concept of "schema" (e.g., Bartlett, 1932; Hebb, 1949) or to Lashley's (1958) trace systems. All permanent events in memory belong to one system or another, but systems may overlap in varying degrees, share subsets of events, or be relatively autonomous. Also, systems vary on a number of dimensions, such as size (how much is known about a subject matter), stability (how reliably the knowledge can be retrieved), and complexity (how detailed the knowledge is). Both content-specific and procedural knowledge are included in a representational system, so that at this level no differentiation is made between structuring the problem in response to cues and dealing actively with an emergency.

It is assumed that information in LTM is latent and that it must first be entered into active memory before it can be processed (Lashley, 1958). This implies that systems can only be altered when they are active, thus, learning (increasing the size of a system) and forgetting (decreasing the size of a system or its reliability) can only take place while the appropriate system is in active memory. It also implies that incoming stimuli (e.g., cues) can only be understood with respect to in-

formation belonging to systems that are active at the time. It is possible for several systems to be active at the same time, depending on their size and complexity, and a cue can be represented in more than one system at the same time; but in general, the most salient cue will activate the system that has its best representation. As a simplification, it is assumed that when relevant cues from the environment are perceived, they serve to activate the representational system that contains the information necessary to process the cue or to understand its meaning. The meaning of a cue is always understood with respect to the system that is active at the time, just as a homonym is interpreted with respect to its immediate context.

There are two ways that a system can be activated. The first was already mentioned, namely, through environmental stimuli that are perceived as being incongruous with those systems that are active at the time. This implies of course, that as long as one is conscious, there is always some system that is active; the problem as far as information processing is concerned, is how to switch from one system to another. The second way is internally. If an element in an active system also belongs to another (inactive) system, that element has the potential of activating the second system.

These minimal assumptions are sufficient to justify some of the training implications to be derived. A more comprehensive model and its implications for learning processes, and hence, for structuring training materials, is described in Hopf-Weichel (1976) and Weichel (1972). It serves as a basis for developing hypotheses concerning how to maximize the probability that relevant information will be available when needed.

This conceptualization makes it possible to deal with the notion of "templates," their role in training and in dealing with emergencies, and

their limitations. Templates may be defined as preplanned responses to emergencies. In the present formulation, a template is a special case of a representational system, which can only be activated when the pattern of the environmental stimuli matches all the elements in the system. It is extremely well-rehearsed and rigid in the sense that individual external elements are not likely to activate other systems. In other words, the correspondence between external events and the elements of the template is highly specific, and the system itself is relatively autonomous, so that it does not tend to activate other systems, and generally it can be activated only by a specified configuration of external stimuli. In this way, responses to these external stimuli are highly reliable and stress-resistant.

There will be times when templates become activated when in fact they do not represent the best solution to the situation. The problem for training is to teach pilots to recognize when the templates are applicable and how to activate the appropriate representational systems for dealing with unplanned emergencies when templates are not appropriate.

7.3 Basic Taxonomic Structure

7.3.1 Introduction. Webster defines "taxonomy" as "the study of the general principles of scientific classification," or alternately, as a "classification; specifically, the orderly classification of plants and animals according to their presumed natural relationships." Implicit in the above is the idea that a taxonomy has some purpose and that classifications are organized according to some underlying principle. A revised definition, therefore, is proposed: A taxonomy is a way to organize components of a subject matter according to an underlying principle which is used for some purpose.

Four basic components have been identified as particularly important in describing an emergency situation and in developing training guidelines appropriate to those situations. The basic components include the situation as a whole, the malfunctions, the cues arising from the malfunction, and the behavior of the pilot. Each component is characterized by a set of attributes having two or more values. These attributes identify the qualities of the components that are important in differentiating among training approaches. The values assigned to the attributes are to a large extent determined by practical considerations and can easily be changed as the need arises. For example, if one of the attributes of behavior is "programmable" and two values (yes/no) are assigned to it, it only means that for the time being these two values are considered a sufficient breakdown in terms of the training guidelines to be developed. However, it might be necessary to assign additional values (e.g., partially programmable) to this attribute if the taxonomy were applied to a specific training situation.

The structure of the taxonomy is not rigid. It is a preliminary attempt to categorize emergency situations in terms of the training needs that are anticipated. These needs will differ, depending on how specific and predictable the behavior of the pilot is, and whether the behavior includes psychomotor as well as procedural, cognitive, and decision-making behavior. As such, the taxonomy represents a general scheme for guiding training development.

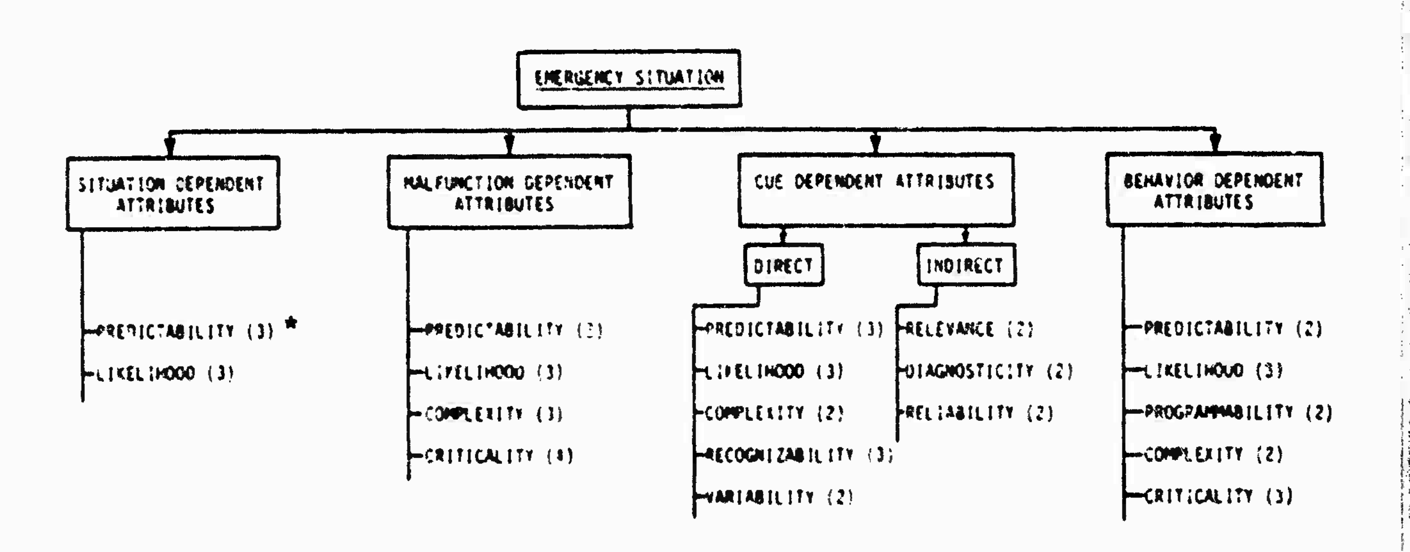
7.3.2 Components and Their Attributes. The components of the taxonomy represent the major categories that have to be described in terms of a set of attribute values. In the present context, attributes are not additive components of utility, rather they represent general features, used as differentiators of situational demands and pointers to subsequent training requirements. The values assigned to the attributes may

be either quantitative or qualitative, and serve to characterize different types of emergency situations. The selection of the attributes was based on their usefulness in distinguishing the categories of the taxonomy, which in turn will serve as a basis in developing guidelines for training and scenario generation.

The components and their attributes are shown in Figure 7-8. While there is an interrelationship between the attributes and their values across components, the values of each attribute are independently assigned to each component. For example, the description and values of the attribute "complexity" need not be the same when it pertains to malfunctions as when it pertains to cues. A description of the attributes and their values follows. This is an initial attempt to describe relevant attributes and values, with alterations and additions to be made in the future, when the taxonomy is put to use.

7.3.2.1 Situation-Dependent Attributes. "Situation" refers to all factors which affect the responses of the aircrew and the outcome of an emergency. This includes mission profile, flight phase, weather, time of day, communications, distance from help, and other relevant factors.

(1) Predictability. All components have "predictability" as an attribute, and in each case, it will have the same description and the same values, namely, "mostly predictable, not predictable, and partially predictable." When any one of the components is predictable, it means that all the factors that are relevant to the emergency can be described and their influence on the emergency predicted. "Predictability" does not imply that the emergency itself can be predicted, but rather that it is possible to specify the influence of each situational factor on the outcome of the



* NUMBERS IN PARENTHESES ARE THE NUMBER OF VALUES ASSIGNED TO EACH ATTRIBUTE

FIGURE 7-8.
COMPONENTS AND ATTRIBUTES OF EMERGENCY SITUATIONS

emergency. For example, an instrument failure in VFR conditions is a very different emergency than in poor weather or at night; in this case, the effects of visual conditions on instrument failure can be described. On the other hand, there may be factors which will affect an emergency situation which cannot be predicted and hence, cannot be included in scenarios. For example, meteorological conditions can produce visual illusions that cannot be predicted. In an accident with a T-37B, a student pilot perceived both fire warning lights illuminated, and noted smoke billowing over the right wing. Later investigation disclosed that the student pilot ejected from a flyable aircraft, possibly due to cockpit glare, which appeared to illuminate the fire warning lights and caused an illusion of smoke. Cases such as these are not likely to be predicted before they actually occur.

Predictability as an attribute is more easily understood with respect to malfunctions or cues. Malfunctions that have not been predicted occur relatively frequently, as evidenced by the Safety Recommendations Bulletins issued by the National Transportation Safety Board (NTSB). Any number of malfunctions can occur that cannot be predicted. For example, a fatigue crack in a tail rotor blade of a Sikorsky S61L helicopter caused a 35-inch outboard section of one of the tail rotor blades to separate in flight, resulting in a massive failure in the tail rotor gear box. The helicopter crashed with fatal consequences. The crack was not detectable by visual examination and the failure could not have been predicted. (The safety board recommended that the airworthiness certificate of the S61 air-

craft be withdrawn until a means of detecting potential tail rotor blade failures could be devised and implemented; NTSB Safety Recommendations A-79-25 and A-79-26.)

(2) Likelihood. This attribute can be assigned any value between 0 and 1, because likelihood refers to the probability that a particular situation will occur, and this can be estimated from frequency data. However, for practical purposes, three values will be used: high, medium, and low. This attribute is important in that it may suggest how much training time should be devoted to a certain combination of events. Likelihood is also an attribute that applies to all four components, and for which the attribute values will remain the same across components.

7.3.2.2 Malfunction-Dependent Attributes. Malfunctions refer to any physical breakdown, failure, or irregularity in the system. The cause of the malfunction is irrelevant at this point, although eventually, the taxonomy should be expanded to include events preceding the onset of a malfunction, since the identification of such causal factors can also lead to the development of better training guidelines. Attributes of malfunctions include:

(1) Predictability. Same as above.

(2) Likelihood. Same as above.

(3) Complexity. The complexity of a malfunction refers to the malfunction itself, its physical repercussions on other parts of the system, and the ease or difficulty with which it can be described. The values include single, compound,

or sequential. A battery failure would be an example of a single malfunction, whereas a total generator failure would be considered a compound malfunction. A sequential malfunction refers to several malfunctions occurring in sequence, whether or not they are directly related to each other.

(4) Criticality. This is an important attribute, which refers to the potential criticality of the emergency situation in terms of its outcome. While both the situation and the cues can vary in criticality, it is the type of malfunction that is the major determinant of an emergency situation's outcome. Criticality has four values: minimal, medium, major and ambiguous. A highly critical malfunction has the potential for a disasterous outcome, with danger to the pilot and/or the aircraft. Medium and minimal refer to correspondingly lower outcome criticalities. These values can be obtained by having experts rate emergency conditions as was described in Chapter 6. A situation having ambiguous criticality is one in which the outcome depends on a combination of factors that are dependent on environmental events (e.g., poor weather makes an instrument failure much more critical than good weather), the system (e.g., the criticality of an engine failure depends on whether the aircraft has one, two, or more engines, and if it has two engines, whether it is the first or the second engine failure), or on the pilot's behavior (e.g., at what point in time the emergency is perceived and dealt with can

determine the criticality of the malfunction). Criticality, just as likelihood, may suggest the amount of training that should be devoted to a particular malfunction or combination of malfunctions.

At the time of an emergency and from the pilot's point of view, the complexity and the criticality of the malfunction are probably not as important as the complexity and perceived criticality of the cues, as exemplified in the following abbreviated report of a minor accident involving a B-52G aircraft:

> Immediately after liftoff, all engine instruments for the right wing engines began erratic fluctuations and several generator circuit breakers opened. During flap retraction, the number 6 engine fire light illuminated and the engine was shut down. The fire light remained on and the number 5 engine throttle was reduced to idle. At this time, the number 8 engine fire light illuminated and the number 8 engine was shut down. Then, the number 5 engine fire light illuminated and the number 7 engine fire light flickered. Due to the low altitude and aircraft gross weight, the aircrew elected not to shut down the numbers 5 and 7 engines. Fuel was burned down and an uneventful six-engine landing was made. The aircraft sustained minor damage.

During the investigation, it was discovered that:

> Some time between engine start through takeoff, the bleed air manifold duct assembly failed due to tensile overloading of an undetermined nature. As a result of the released hot bleed air, wire bundles in the right wing leading edge burned or melted resulting in multiple, unrelated, serious aircraft malfunction indications.

Here the cues were complex and appeared highly critical, even though the underlying malfunction was simple and of low criticality. This suggests that the aircrew's behavior must first be guided by the cues, and only secondarily by their evaluation concerning the nature of the malfunction.

7.3.2.3 Cue-Dependent Attributes. A cue is any manifestation in the pilot's environment that is unexpected and that is perceived through any of the senses. Cues are conceptualized as patterns of information that are described in terms of a set of attributes. Because cues represent information concerning the malfunction, several of the attributes refer to the relationship between the cues and the malfunction (indirect attributes), rather than to the cues themselves (direct attributes). This is an important aspect of an emergency, which is categorized separately in the taxonomy and which must be emphasized during training. The interpretation of cues is not only a function of training however, but also of general and specific experiences with the aircraft. Much research remains to be done before all their relevant characteristics can be included in scenarios although the following attributes are believed to be important:

Direct Attributes.

(1) Predictability. Same as above.

(2) Likelihood. Same as above.

(3) Complexity. The complexity of cues is interpreted differently than the complexity of malfunctions. Malfunctions can be described objectively, whereas cues are only meaningful as they are perceived and interpreted by the pilot.

Only two values are assigned to the complexity of cues: simple and complex, and they refer to the number of cues perceived and used in diagnosing an emergency. The relative salience of the cues to each other is included under complexity.

(4) Recognizability. Recognizability or salience refers to the probability that a particular cue will be perceived and the time required to perceive it. Although this is a continuous variable, only three values will be assigned: cues have a high, medium, or low probability of being recognized. Recognizability is a function of the perceptual sensitivity of the operator, as well as of the information load existing at the time, which includes the complexity of the total pattern of cues.

(5) Variability. Variability refers to the fact that some cues are static, while others are dynamic; i.e., they change over time. These are the only two values assigned to this attribute. For example, a warning light is a static cue, whereas gauge fluctuation is dynamic, since the degree of fluctuation can increase or decrease over time.

Indirect Attributes: Cue/Malfunction Relationship.

(1) Relevance. Some cues are relevant and some are irrelevant in diagnosing a malfunction; these are the two values of this attribute.

(2) Diagnosticity. While relevance is an attribute that characterizes individual cues with respect to the malfunc-

tion, diagnosticity refers to the pattern of available cues: the pattern may or may not be diagnostic in identifying a malfunction. That is, a given pattern of cues may be very characteristic of a malfunction, or it may be puzzling, in the sense that some of the cues in the pattern suggest one malfunction, while others suggest a different malfunction.

(3) Reliability. This attribute is assigned two values, reliable and not reliable. When a cue is reliable, it consistently indicates the presence of a particular malfunction and when it is not reliable, it may or may not suggest the presence of a given malfunction.

These cue/malfunction relationships were enumerated in an attempt to identify all possible characteristics that may be important in categorizing emergency situations. In practice, however (at least for the time being) only two attributes will be used which subsume those listed above:

(1) Complexity. The pattern of cues is complex or not complex with respect to the malfunction.

(2) Congruity. There is a congruous or an incongruous relationship between the cues and the malfunction. If the relationship is congruous, the cues rather easily identify the malfunction (their pattern is reliable), whereas, if the relationship is incongruous, they represent a puzzle as to the identity of the malfunction.

7.3.2.4 Behavior-Dependent Attributes. Behavior includes overt actions, as well as decision making and other types of cognitive processes. The attributes that are important to the taxonomy and to the development of training guidelines are as follows:

(1) Predictability. Behavior is predictable or not predictable. When it is predictable, the components of the behavior required to deal with an emergency can be specified. This does not include entire sequences of behavior, strictly organized and prescribed. When behavior is said to be predictable, it is possible to specify, in general, which types of actions and decisions will be necessary.

(2) Likelihood. This refers to the probability that a sequence of actions will be utilized in response to an emergency. The amount of training and testing of such actions is determined by the value of this attribute which has three values: high, medium, and low.

(3) Programmability. Behavior is programmable or not programmable. Programmable behavior is characteristic of the actions prescribed by Boldface procedures in that entire sequences of actions can be specified and trained in advance of the emergency. Programmed behavior typically does not include complex cognitive components.

(4) Complexity. Complexity refers specifically to the complexity of the decisions that are involved in a particular situation and has two values, simple and complex.

(5) Criticality. Criticality, with respect to behavior, refers to the amount of time available to perform an action. Some emergency situations are highly time-critical, while others are not, but this attribute affects the behavior rather than the situation itself. Criticality has three values: high, medium and low. High time-criticality refers to situations in which only a few seconds are available to make a decision or take an action. If a situation has medium time criticality, there is some time pressure involved, but there is still enough time to evaluate the situation and consider alternatives, whereas in low time-critical situations, this attribute is for practical purposes insignificant.

7.4 Initial Training Guidelines

7.4.1 Theoretical Derivations. The taxonomic structure that has been described presents a number of attributes that can be considered in the design of emergency training programs, and in particular, emergency training materials and mission scenarios. One attribute in particular, predictability, is a key element in describing or classifying the components of an emergency. As defined earlier, predictability refers to the specificity with which details of an emergency situation can be described and the appropriate response behaviors can be prescribed. Other attributes, of course, have implications for training program design. However, predictability, because of its central role in the representative models presented, will be explored in the remainder of this section as one guiding principle for emergency training program development.

Three major classes of emergency situations can be identified, depending on the degree of the predictability of their components. The general structure of these situations is shown in Figure 7-9. The levels of representation and the relevant components for each, are listed in the left-hand columns. For each level of representation and its appropriate components, the attribute values are specified for each of three situations. The three situations are simply labeled "predictable," "partially predictable," and "not predictable," or situations 1, 2, and 3, respectively. In Figures 7-10, 7-11, and 7-12, the appropriate attribute values for each situation are shown separately.

Figure 7-10 defines situation 1, in which the events, the behavior, and the outcomes are predictable. In general, only single malfunctions will fall into this category, and their cues will be well-defined, recognizable, and will have high diagnosticity and reliability. These values imply that there is a simple, congruous relationship between the cues and the malfunction. When this is the case, very little decision-making is necessary at the time the malfunction is diagnosed; at the most, some problem recognition and structuring may be required. Since the event sequence is well-defined and predictable, the best decision rule can be determined at the time the event sequence is described, as can the most appropriate responses.

The cognitive structure implicit in this type of situation is that of a single template that contains all the information necessary to recognize the malfunction and to deal with it. Thus, the process is one of recognition and of matching the correct template to the situation. The implication for training is essentially the same as that underlying Boldface procedures. The entire pattern of cues must be trained so thoroughly that the correct responses to it are immediate. In some cases, there may be some fuzzy boundaries between two or more cue pat-

REPRESENTATION (MODELS)	COMPONENTS	SITUATION 1 PREDICTABLE	SITUATION 2 PARTIALLY PREDICTABLE	SITUATION 3 NOT PREDICTABLE
EVENT-RELATED FACTORS	MALFUNCTIONS CUES MALF./CUE RELATIONSHIP	(see Figure 7-10)	(see Figure 7-11)	(see Figure 7-12)
DECISION-THEORETIC FACTORS	DECISIONS DECISION RULE RESPONSE TYPE			
COGNITIVE FACTORS	COGNITIVE STRUCTURE COGNITIVE PROCESSES			
IMPLICATIONS	TRAINING REQUIREMENTS			

FIGURE 7-9.
COMPONENTS OF REPRESENTATIONAL MODELS USED TO STRUCTURE EMERGENCY SITUATIONS IN TERMS OF THEIR PREDICTABILITY

COMPONENTS	SITUATION 1
MALFUNCTIONS	SINGLE
CUES	WELL-DEFINED, RECOGNIZABLE
	HIGH DIAGNOSTICITY
	HIGH RELIABILITY
MALF./CUE RELATIONSHIP	CONGRUOUS, SIMPLE
DECISIONS	PRE-PROGRAMMED, TYPE I
DECISION RULE	PRE-PROGRAMMED ("BEST")
RESPONSES	PROGRAMMED
COGNITIVE STRUCTURE	SINGLE TEMPLATE (MALFUNCTION AND PROCEDURE)
COGNITIVE PROCESSES	RECOGNITION, TEMPLATE MATCHING
TRAINING	BOLDFACE
REQUIREMENTS	QUICK RESPONSES
	SOME DECISION TRAINING FOR PROBLEM RECOGNITION AND STRUCTURING

FIGURE 7-10.
COMPONENTS OF SITUATION 1 EMERGENCIES

COMPONENTS	SITUATION 2
MALFUNCTIONS	A) SINGLE B) COMPOUND C) SEQUENTIAL
CUES	A) AMBIGUOUS; B) AND C) WELL-DEFINED OR AMBIGUOUS
MALF./CUE RELATIONSHIP	CONGRUOUS AND COMPLEX
DECISIONS	A) TYPE 1 B) TYPE 2 C) TYPE 3
DECISION RULE	CAN BE SELECTED
RESPONSES	PREDICTABLE, BUT NOT PROGRAMMED
COGNITIVE STRUCTURE	SEVERAL TEMPLATES
COGNITIVE PROCESSES	RECALL, TEMPLATE INTEGRATION, DISCRIMINATION JUDGMENT
TRAINING REQUIREMENTS	SET, GRADUATED DECISION TRAINING
	FLEXIBILITY (FAST "SWITCHING" OF TEMPLATES)
	DIVERSITY (GENERATION OF LOW-PROBABILITY TEMPLATES)

FIGURE 7-11.
COMPONENTS OF SITUATION 2 EMERGENCIES

COMPONENTS	SITUATION 3
MALFUNCTIONS	UNPREDICTABLE, PROBABLY COMPLEX
CUES	COMPLEX, UNCERTAIN, AMBIGUOUS
MALF./CUE RELATIONSHIP	INCONGRUOUS - SIMPLE OR COMPLEX
DECISIONS	TYPE 3 ONLY
DECISION RULE	"ASSUME THE WORST CASE" AND MINIMIZE RISK
RESPONSES	UNPREDICTABLE, NOT PROGRAMMED
COGNITIVE STRUCTURE	NO TEMPLATES
COGNITIVE PROCESSES	JUDGMENT
	CREATIVE PROBLEM SOLVING; HIGH DEGREE OF INTEGRATION REQUIRED BETWEEN ELEMENTS IN LTM
TRAINING	SET
REQUIREMENTS	TRAIN FOR RECOGNITION OF LOW-PROBABILITY EVENTS AND RELATIONSHIPS
	HIGH EMPHASIS ON PERSONAL DECISION RULE

FIGURE 7-12.
COMPONENTS OF SITUATION 3 EMERGENCIES

terns, so that some training in problem recognition and structuring will be required to deal with malfunctions belonging to situation 1.

Figure 7-11 lists the attribute values for the partially predictable situations. These are situations that can be foreseen, but for which decisions cannot be rigidly programmed because there are too many potential complexities that affect the decisions and the actions involved. Three types of malfunctions can belong to situation 2: single, compound, or sequential. If a malfunction is single, it has to have ambiguous cues to be categorized in situation 2. Ambiguous cues are those that suggest either no specific malfunction, or more than one malfunction, so that the cue/malfunction relationship is complex. If the malfunctions are compound or sequential, the cues can be either well-defined or ambiguous.

To some extent, compound and sequential malfunctions can be predicted, but the number of possible combinations is so great that it is not possible to present all combinations in a training course. For this reason a more generalized approach to decision training may be necessary. All three types of decision tasks (problem structuring, alternative selection, complete decision), as well as the rules for selecting the best decision, must be trained for, so that pilots will be able to evaluate applicable procedures and rules at the time of the emergency, rather than to rely on inappropriate or overly rigid prescribed responses. Desired responses are predictable in the sense that generic situations can be devised for training, but not programmed to the level of detail of a specific behavioral sequence which applies to each unique situation.

The cognitive structure underlying situation 2 emergencies consists of several templates, or of representational systems with overlapping ele-

ments, so that feature recognition and integration of the information from several sources is necessary. This requires more active recall than the simple recognition and matching of situation 1 emergencies. Because the set of potential situations belonging to this category is very large, training materials must be carefully structured and carefully controlled to ensure that all essential factors are included, and that they are graduated with respect to their difficulty. Most emergencies that occur will fall into this category since most accidents that do take place are the result of repeated causes with known precedents (Parker, 1978) but varying in situational detail.

Figure 7-12 presents the conceptualization of unpredictable situations. The malfunctions are unpredictable and probably complex. The cues may be complex, but they are certainly ambiguous because if the malfunction cannot be foreseen, the cues will probably not display a recognizable pattern. If the cue pattern is recognizable, it may be misleading, so that the relationship of the cues to the malfunction will be incongruous. In these cases, only complete decisions (Type 3) will be appropriate, and an appropriate decision rule is to minimize the risk and to assume the worst possible outcome. No templates will be available to deal with this situation, but a high degree of integration between disparate representational systems will be required. Effective responses may be compared to creative problem solving, namely, to apply old solutions to problems that have never been encountered before, or to induce the occurrence of uncommon responses. The training requirements are similar to those for situation 2 emergencies, but they must emphasize this added creative aspect--practice in generating low-probability events and procedures. This emphasis can be achieved by presenting simulated situations that require unusual solutions and by reinforcing the use of such solutions. Techniques for eliciting low-probability responses have been described by Maltzman (1960) among others.

7.4.2 Review of Training Implications. The three classes of emergency situations described above were categorized according to their predictability because of the central role this attribute plays in the representations and taxonomic structure developed for aircraft emergencies. Figure 7-13 is a brief overview of the three classes of emergencies in terms of the taxonomic structure together with training implications for each class.

For Situation 1, Boldface-like training appears to be relevant, assuming the presence of time and safety criticality. These emergencies involve straightforward relationships between cues and malfunctions, information processing requirements are low, and response procedures are known and programmable.

For Situation 2, explicit training in decision techniques is recommended since a less predictable set of circumstances and responses is involved than in Situation 1. Cues are complex and/or ambiguous with respect to identifying malfunctions. More information processing is required, and responses can not be fully programmed ahead of time. Training techniques which emphasize integration of several cognitive representational systems appear to be recommended.

In Situation 3, cues can be complex, ambiguous, and perhaps misleading. Responses are not programmable ahead of time and extensive deliberation may be necessary to diagnose the situation and develop an appropriate response. Training for these emergencies must address the ability to integrate disparate representational systems and to account for low probability events and relationships. Development of personal decision rules, in which the pilot establishes techniques for dealing with manageable approximations of complex situations, also appears to be recommended.

	SITUATION 1	SITUATION 2	SITUATION 3
MALF./CUE RELATIONSHIP	CONGRUOUS SIMPLE	COMPLEX CONGRUOUS	INCONGRUOUS
RESPONSES	PROGRAMMED	NOT PROGRAMMED, PREDICTABLE	NOT PROGRAMMED, NOT PREDICTABLE
COGNITIVE PROCESSES	TEMPLATE MATCHING	TEMPLATE INTEGRATION	CREATIVE PROBLEM SOLVING
TRAINING IMPLICATIONS	BOLDFACE QUICK RESPONSES SOME DECISION TRAINING FOR PROBLEM RECOG- NITION AND STRUCTURING	SET, GRADUATED DECISION TRAINING FLEXIBILITY (FAST "SWITCHING" OF TEMPLATES) DIVERSITY (GENERATION OF LOW-PROBABILITY TEMPLATES)	SET, TRAINING FOR RECOGNITION OF LOW PROBABILITY EVENTS AND RELATIONSHIPS HIGH EMPHASIS ON PERSONAL DECISION RULE

FIGURE 7-13.
OVERVIEW OF INITIAL TRAINING GUIDELINES

The present report describes an approach to the application of theoretical models in the development of training requirements. The taxonomy represents a framework for combining theoretical implications into a set of hypotheses relevant to decision making and cognitive behavior in emergency situations. The three situations proposed here are differentiated on the basis of the degree of predictability of the types of responses necessary to deal with various emergency conditions. Other attributes may also have differential implications which need to be explored and applied to the development of training guidelines.

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APPENDIX A

THIRTY MINUTES OVER FLORIDA

THIRTY MINUTES OVER FLORIDA

Case Study

Lieutenant Mike Bryant, stationed at North Island NAS, Squadron VS41, San Diego, was flying over Florida on December 9, 1978, when he experienced a pending dual engine failure. He was flying an S-3 and had a student as a co-pilot. At that time, Lt. Bryant had approximately 2000 hours of flight time in S-3s and S-2s, and had already experienced 11 engine shutdowns, which represents an above average amount of experience.

Approximately forty-five minutes into the flight, leveling off at 28000 feet, with an airspeed of nearly .65 mach (normal cruise speed), Lt. Bryant and his co-pilot were just preparing to put on their oxygen masks--a precautionary measure required above 27000 feet in case the large side canopies depart the aircraft--when they smelled smoke. Though oxygen masks are very important (because at these altitudes conscious time without the masks is only a few seconds in the event of a large side canopy departure), had they been wearing them, they would not have been able to smell the smoke.

Because of the construction of the bleed air system in the S-3, it is not uncommon to smell some smoke, and Lt. Bryant did not attach too much importance to it. The slight smell of smoke continued for a few minutes; and, in addition, the #2 engine gauges started to fluctuate a bit. Again, this is not too uncommon. The probability of getting a whiff of ECS (Environmental Control System) exhaust in the cockpit of the S-3 is quite high; it happens every day, but usually at lower altitudes. It is equally as common for the gauges to fluctuate a little (due to a loose wire, for example) but it is not common for all the

gauges to fluctuate at the same time. This was the first significant cue which started the process of problem recognition. In the S-3, there are six primary gauges for each engine, four tape gauges and two dial gauges, one for the oil pressure and one for the hydraulic system. Thus, while Lt. Bryant was not particularly worried at this time, he became aware that something might be amiss. There was a little more smoke and a little more fluctuation of the gauges. Every indication of a problem was increasing.

All of a sudden, there was a lot more smoke, and all the gauges except for the oil pressure gauge, were fluctuating wildly. The fluctuations indicated that something was wrong in the core section of the engine, especially since there was also smoke in the cockpit. All the cues suggested that the #2 engine was coming apart. The fact that the oil pressure gauge was not fluctuating was not significant; normally, it is just a matter of time before it too begins to fluctuate.

Patterns of gauge abnormalities can vary, yet they all point to a pending engine failure. For example, a loose oil pump or a massive leak will cause the oil pressure gauge to drop off, while all other gauges will still look normal. In either case, if a decision has to be made, one has to assume that such gauge abnormalities indicate a pending engine failure. This is not a catastrophic problem in the S-3 since it has two engines and flies equally well with a single engine. Little power and only an insignificant amount of airspeed is lost, which is traded off for altitude. Thus, Lt. Bryant shut down engine #2 and started the descent to avoid pressurization problems. This decision represents a Type 1 decision, consisting primarily of problem recognition and structuring, but not requiring alternative generation and selection, since there was really only one viable option.

Of course, there was an alternative, namely not to shut down the engine at all. However, given the indications of smoke and gauge fluctuations which suggested an internal compression or turbine section failure, the possible consequences of not shutting down the engine were all at least as serious as shutting it down. These particular cues did not point to a specific malfunction; they simply indicated that something was wrong, but given such general cues, one must anticipate the probability of an explosion, a fire, or a flame-out. The probability of an explosion is almost zero, since it has never happened, but due to the large amount of fuel available, there is a fairly high probability of a fire when a non-specific engine malfunction occurs. The criticality of engine fire is not as high in the S-3 as in the F-4 and the F-14, for example, because fires can be isolated more easily in airplanes with pod-mounted engines, such as the S-3, than with fuselage-mounted engines, as in the F-4 and the F-14. In either case, however, a fire is to be avoided as it can only cause more damage to the engine. The third possible outcome is a flame-out which would have the same effect as an engine shut-down.

It is also possible that, given general cues indicating a possible engine failure, nothing would in fact happen, but the general philosophy in a case like this, is to assume the worse. Thus, at this point, the only real alternative available for Lt. Bryant was to shut down the engine. In general, if one has two engines and something goes wrong with one of them, one simply shuts it down, because the probability that both engines will fail is infinitesimal; in fact, in the 5-year history of the S-3, this has never happened.

After shutting down one engine, the standard procedure requires the pilot to land as soon as possible. This is a Boldface requirement which will be followed in the majority of cases, although there can be exceptions. For example, if a pilot is flying over enemy territory, he may

decide not to land as soon as possible. That is, while the phrase "land as soon as possible" is a Boldface requirement following well-defined emergencies, it is subject to varying interpretations, and in this sense, represents a personal decision rule.

In Lt. Bryant's case, there were no extenuating circumstances which would have prevented him from landing as soon as possible. His next decision therefore, involved the evaluation of the various landing possibilities. The landing decision is a clear case of a Type 2, multi-attribute decision. There is no problem recognition or structuring involved, but there are several alternatives which have to be evaluated on a number of different attributes. The most important in cases of emergencies is distance, in compliance with the directive to land as soon as possible, although there are other considerations, such as weather, facilities available, and type of airfield. The type of emergency, the severity of the weather, the difference in the distances between airfields, the availability of arresting gear and crash crews, are all factors which must be weighed against the distance of the closest airfield.

For Lt. Bryant, the choice was relatively simple. There were two Navy bases and two Air Force bases in the area. Other factors being equal, a Navy base would be selected over an Air Force or a civilian base, because a Navy base has the appropriate maintenance facilities. Lt. Bryant's maintenance crew was at Cecil Field, about 150 miles away, and was his preferred alternative with respect to the available facilities. However, there was a cold front between Cecil and the S-3 and Cecil was experiencing heavy rains. The other Navy base was at Pensacola, about 100 miles away. Both these fields were farther than the two Air Force bases: Eglin, about 80 miles away, and Tyndall, about 50 miles away. In this case, Tyndall had the best options with respect to all factors, including distance. If Tyndall had been closed because of bad weather,

the second choice would have been Pensacola, a Navy base, rather than Eglin. Even though Eglin was 20 miles closer, it is very large and has several landing areas which makes it undesirable because a pilot cannot know ahead of time exactly where he will be directed to land. "They can vector you to maybe 90 miles away," according to Lt. Bryant.

Arresting gear was available at all four airfields. For Lt. Bryant, this just represented an extra safeguard; he could have landed without it. However, if engine #1 had failed instead of engine #2, an arrested landing would have been mandatory because the functioning of the utility hydraulics--which includes the main brake system, nosewheel steering, and the landing gear extension--depends on engine #1. Thus, the landing decision does not only depend on the characteristics of the available landing areas, but also on the type of emergency necessitating a landing.

Following the shut-down of engine #2, Lt. Bryant had declared an emergency with Jacksonville Center, the controlling agency, which also provided him with the information concerning the distances of the various airfields. He had the capability of calculating these distances himself, but obtaining them from Center is easier and faster. He remained in continued radio communication with Center but does not remember asking for any further advice because the events became somewhat hectic at that time. At approximately 9000 feet, on his descent towards Tyndall, the whole aircraft started to vibrate; engine #1 was acting up severely and appeared to be failing as well. There was a lot of noise, and now, there was really cause for concern. The loud, low-pitched rumbling sounds and the high rate of vibration are typical cues pointing to an impending catastrophic engine failure, and were very different from the cues which had led to the shut-down of engine #2 (the fluctuation of the engine gauges and the smell of smoke). Since these indications were

much more serious, the best alternative was to restart engine #2. Lt. Bryant tried this three times, but without success.

Since engine #2 could not be restarted, Lt. Bryant had several options; he could try and land immediately on the nearest highway, he could eject, or he could keep flying. Experience and confidence enabled him to choose the latter option, as long as the airplane had enough power and enough speed to keep flying. This is also a personal decision rule; Boldface procedures do not cover contingencies such as these. At this point, however, the decision to keep flying also implies that criteria have to be defined for ejecting if it becomes necessary. These criteria are highly subjective and include the perception of significant changes in the noise level, the amount of vibration, and changes in the engine gauges. With a distance of only 20 miles remaining to reach Tyndall, Lt. Bryant decided to start ejection procedures if the engines "got any worse." What is important here is to know what the criteria are and to follow through when the criteria are reached. Lives may be lost, not because the pilot does not know how to set the criteria, but because he does not follow through with his decision, or because he changes his mind at the last minute.

As they approached the field, Lt. Bryant had to consider the factors involved in landing his airplane under these conditions. Air Force regulations and the GCA controllers wanted him to do a 10-mile straight-in, which would have been normal for the type of weather they had. However, this is a radar-controlled approach and Lt. Bryant wanted a visual approach with a single radar vector and a 3-mile straight-in. There were gusty cross-winds of at least 25 knots, but the conditions were VFR. Lt. Bryant was able to see where the field was located and he had already reviewed the schematic charts of the airport. Under these conditions, a visual approach did not present any danger; on the contrary, it

was much more expeditious because he could reach the field and the ground faster than if he had had to wait for a radar-controlled approach for which vectors have to be calculated. Even though the type of approach is generally decided by ground control, the pilot always has the option to override this decision, and Lt. Bryant's primary concern was not to lose any time whatsoever. During the hectic conditions of the last 20 miles, Lt. Bryant and his co-pilot had followed all the procedures in the check-list for a precautionary landing, but on final approach, realized that they had forgotten to dump gas. Since the S-3 was a little too heavy for the type of landing selected, gas was dumped on final approach and they landed.

Following an emergency landing of this type, normal procedures require that the engines not be shut off until the crash crew arrives. However, upon arriving at the field, the whole cockpit was suddenly, and very rapidly, full of smoke. Lt. Bryant shut down the APU (auxiliary power unit) and engine #1, and he and his co-pilot left the cockpit head first. This much smoke can be an indication of fire, but because of the relationship of the cockpit to the engines, this cannot be visually verified and the best alternative is to leave the aircraft as soon as possible. After verifying that the engine was not on fire, Lt. Bryant returned to his airplane, which was then towed back to the hangar.

Because all instructors at VS-41 are qualified as maintenance check pilots as well, Lt. Bryant proceeded to investigate the source of the problem. He contacted his maintenance crew at Cecil and, by phone, discovered that the failure had occurred in the ECS turbine. Such a failure can cause a backup in the bleed air system (the back pressure can overbleed the engines), explaining the smoke in the cockpit when the

air-conditioning system was on. This was not a classic failure; in fact, the ECS turbine had never failed in this particular way before.

After Lt. Bryant discovered what had caused the emergency, he decided to fly back to Cecil. He did not consider it a risky decision, as long as the air-conditioning system was not used.

Analysis

This entire incident, which is summarized in Figure A-1, lasted only about 30 minutes. During that time, numerous decisions had to be made, only a few of which may be considered Boldface procedures. At no time, however, was there any real time pressure, in the sense that a decision had to be made within a few seconds. A split-second decision would have been necessary in case of ejection. This is the reason that predetermined criteria for ejection are so important; a pilot has to know which changes in the pattern of cues will cause him to make the ejection decision. Experience and confidence seem to be a requisite for success.

In Lt. Bryant's case, the most crucial decision occurred when engine #1 started to act up. There are different ways in which an engine can "act up," and the evaluation is always very subjective. The cues have to do with fluctuations, noise, smell, feel, torque, vibrations, sound. It is possible to distinguish between different malfunctions from the way the engine "acts up," but there are several different patterns of cues which point to engine failure. Some patterns of cues are more predictive of malfunctions than others.

From the cues that he did have, Lt. Bryant had to assume that engine #1 was failing. There were no other cues he could have used to disconfirm this belief, although there could have been cues which would have con-

	DECISION ANTECEDENT	DECISION TYPE	FACTORS	ALTERNATIVES	CHOICE MADE	RISK
1.	Smell of smoke	Problem recognition	History (some smell of smoke is normal) Altitude	Investigate Ignore	Ignore	Minimal
2.	Smell of smoke continues All gauges fluctuate a little except oil gauge	Problem recognition	History Information value of cues	Investigate Wait	Wait	Medium
3.	Increased amount of smoke Oil gauge fluctuation	Problem recognition Problem structuring	Pattern pointing to engine failure Possibility of explosion	Continue Land on highway Eject Shut down engine #2	Shut down engine #2	Medium (engine #1 is still running)
4.	Engine shut-down	Boldface		Land as soon as possible	Land as soon as possible	Minimal
5.	Need to land	Alternative selection	Distance of nearest airfield Weather Facilities (arresting gear and crash crew) Type (Navy, Air Force, civilian) Size of airfield Type of emergency	Cecil (150 miles) Pensacola (100 miles) Eglin (80 miles) Tyndall (50 miles)	Tyndall	Minimal
6.	Engine #1 begins acting up Vibrations throughout aircraft Loud, low-pitched rumbling sounds	Problem recognition Problem structuring Alternative evaluation Alternative selection	Engine #2 is out Pending dual-engine failure	Continue (land as soon as possible) Land on highway Eject Restart engine #2	Restart	High
7.	Failure of restart attempt	Alternative selection Define ejection criteria (Anticipatory decision)	Pending dual-engine failure	Continue (land as soon as possible) Land on highway Eject	Continue	High

FIGURE A-1.
SUMMARY OF EVENTS AND DECISIONS IN S-3 EMERGENCY

DECISION ANTECEDENT	DECISION TYPE	FACTORS	ALTERNATIVES	CHOICE MADE	RISK
8. Type of landing	Alternative selection	Weather Visibility Communication with GC Amount of time needed to land	Radar-controlled 10-mile straight-in Visual approach	Visual approach	Medium
9. Safe landing, but cockpit full of smoke	Problem structuring Alternative selection	Information value of cues Possibility of fire/explosion	Wait for crash crew Shut down engine	Shut down engine	High
10. Cockpit full of smoke	Alternative selection	Information value of cues Possibility of fire explosion	Stay in aircraft Get out	Get out	High
11. Evaluation and diagnosis of malfunction	Problem structuring Alternative selection	ECS turbine malfunction	Wait for maintenance crew Fly back to Cecil	Fly back	Minimal

FIGURE A-1. (CONTINUED)
SUMMARY OF EVENTS AND DECISIONS IN S-3 EMERGENCY

firmed it: if the engine had started to deteriorate, the engine gauges would have indicated it; or if the smoke had continued and had not dissipated, it would have represented confirming evidence of a pending engine failure; other cues could have included various warning lights being illuminated.

In retrospect, it was discovered that no malfunction had been present in either engine, but rather, that the malfunction was in the ECS turbine. A failure or a hot spot in the ECS turbine should have activated a warning light; the fact that it did not seems to indicate that the ECS turbine simply did not get hot enough to activate the light. Instead, the failure generated cues which were quite misleading.

An obvious question is why engine #2 did not restart. Apparently, this was due to a peculiarity of this particular failure which caused an over-bleed of both engines. This should not have happened, because there are valves in the engines which should have by-passed the bleed air. The valves should have opened to extract the excess bleed air overboard. It is assumed that the valves could not handle that much bleed, but the reason for this is not yet known. An engineering investigation is presently in progress.

The relationship between the pending failures of the two engines is interesting with respect to the problem of relevant cues. The cues which suggested that engine #1 was acting up were very different from those which had suggested a failure in engine #2. The cues to engine #2 were the fluctuations of the gauges, coupled with the smell of smoke in the cockpit. The cues with respect to engine #1 were a loud, low-pitched rumbling sound and a lot of vibration, which Lt. Bryant associated with engine #1 only because engine #2 had been shut down. There was a little fluctuation of the engine #1 gauges, but this could easily have been at-

tributed to the vibration. Thus, if both engines had still been running, the cues would still have indicated a typical engine failure, although it would not have been clear which engine was failing.

Both sets of cues, which were very different, could only be interpreted as a pending engine failure. Because a jet turbine or a small ECS turbine basically fail very similarly, as far as the sensors are concerned, one must assume the worst, and Lt. Bryant had to act on that assumption. But if engine #2 had in fact restarted when he tried it, he would have had to make another decision, namely, whether to keep both engines running or whether to shut one of the engines down. He would have shut down engine #1, since its symptoms were much more serious than those of engine #2.

However, if engine #2 had restarted and he had shut down engine #1, everything would have pointed to an ECS failure, because the noise would have continued and he would have realized that it was not due to the #1 engine. In that case, he would have restarted engine #1, and re-evaluated his landing decision. It would not have been as critical to land as soon as possible and the decision would probably have been to land as soon as practical.

Following his experience, Lt. Bryant gave a seminar to other S-3 pilots and wrote up the incident for the Navy URS (Unsatisfactory Materiel Reporting System), a procedure designed to insure dissemination of information relevant to all phases of flying.

To some extent, he also formulated a new personal decision rule, namely--given a recurrence of these symptoms--to first turn off the ECS so as to eliminate at least one hypothesis in diagnosing the malfunction. Turning off the ECS implies reducing one's altitude first, so as

to avoid physiological problems, or alternately, one can wear an oxygen mask while flying without the ECS. Wearing an oxygen mask, however, implies the loss of important olfactory cues, hence a reduction in the amount of information available to decide on the best alternative.

This case study illustrates the complexity of the problems pilots may be faced with and the variety of decisions, some of them under stressful conditions, they may have to make. By combining the results of case studies with theoretical analyses of decision making and of cognitive processes, a better understanding may be reached of the optimal behavior required in aircraft emergency decisions, which may serve as a basis for developing improved training materials.